

DETAILS OF CYANIDE PRACTICE

BY

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PREFACE

The chapters presented in this book are the record of an investigative tour of the principal cyaniding mills of North America, taken with the idea of presenting detailed facts about the present state of the process to the readers of the *Engineering and Mining Journal*, in which periodical they have already appeared. Actual description has been considered of less importance than discussion and correlation of facts gathered from widely different places, the intention having been to present facts and personal opinions, clearly indicated as such, in a form calculated to inform the profession in general and to promote discussion respecting details involving diverging practice. Some pages of the discussion elicited have been included as illuminating the subjects.

One article, that constituting Chapter II, has been included that I did not write. Although I had visited and studied the plant discussed, and had formulated a paper treating of its interesting points, the description and explanation submitted by Mr. R. B. Watson, manager of the Nipissing Mining Co., was used, a manager being more thoroughly familiar with his own plant than anyone else could be. Some points which particularly attract the attention of the outsider, however, were mentioned in my discussion of the subject, and these are to be found constituting Chapter III. Those points thoroughly covered by Mr. Watson have been removed from my article, which makes it somewhat disjointed, but anyone reading the two chapters will be at no trouble to understand the references.

The original itinerary of this technical journey included a visit to the important plants of Mexico, but the condition of affairs in that country when the trip was undertaken, made it necessary for that part to be postponed until such time as there will be more to study and greater safety in traveling.

Any benefit which the profession may derive from the matter presented is to be credited to Mr. Walter Renton Ingalls, Editor of the *Engineering and Mining Journal*, to whose energy and progressive spirit the undertaking is due.

H. A. MCGRAW.

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DETAILS OF CYANIDE PRACTICE

CHAPTER I

THE COBALT DISTRICT, ONTARIO

The mining district of Cobalt in Ontario, Canada, is one of the newer areas in which economic mining has proved possible. In common with most new camps the first output was high-grade material, but it differs from many in the fact that the average content of the mineral has continued up to this time to be higher than is usually the case when work has been carried to the extent that it has here. The valuable metal is silver which occurs native and in combination. It is found as sulphide, arsenide, antimonide and in combination with manganese, nickel and cobalt. Small proportions of copper are also found in some of the ores and in at least one, the Nipissing, mercury has been definitely proved to exist. In regard to the latter many engineers are skeptical, having never encountered any indications of it even in the higher grade mineral but the work of the metallurgists who experimented upon the ores of the Nipissing mine has been sufficient for them to state positively that a small quantity of mercury does exist as a mercury-silver amalgam.

Character of Ore.—The ores occur in narrow fissures in a country rock of fine-grained conglomerate, slate or diabase. They are all hard and tough and are not easily ground to a fine state. The experience of the camp has been that when the ores are ground extremely fine, even to a point where they will pass a 200-mesh screen, the product is largely granular and has the property of settling quickly, the light, flocculent product generally called true slime being conspicuous for its rarity. In addition to this, the mineral is extremely heavy, so that the difficulty of obtaining a product which may be treated as a total slime is greater than is usually the case with silver ores. The power and care required to keep it in suspension is comparatively great.

Most of the mills in the Cobalt camp are concentrators and due to the character of the mineral, which is favorable to concentration, good results have been obtained from this system of treatment. The silver occurs, as has been mentioned, in heavy minerals which give up a large percentage of their silver content on the concentrating table. Nevertheless, the tailing discarded by the concentrating mills contains sufficient silver so that its extraction, or partial extraction, by cyanidation while the pulp is in motion through the mill, might be expected to repay more

than the additional expense of cyanide treatment. It is altogether likely that the average tailing from a concentrator treating 25- to 35-oz. ore will contain not less than five to eight ounces of silver per ton. Most of the operators will not admit that the tailing runs so high, but a consideration of the conditions, together with some frank conversation with operators leads me to believe that these figures do not overstate the case.

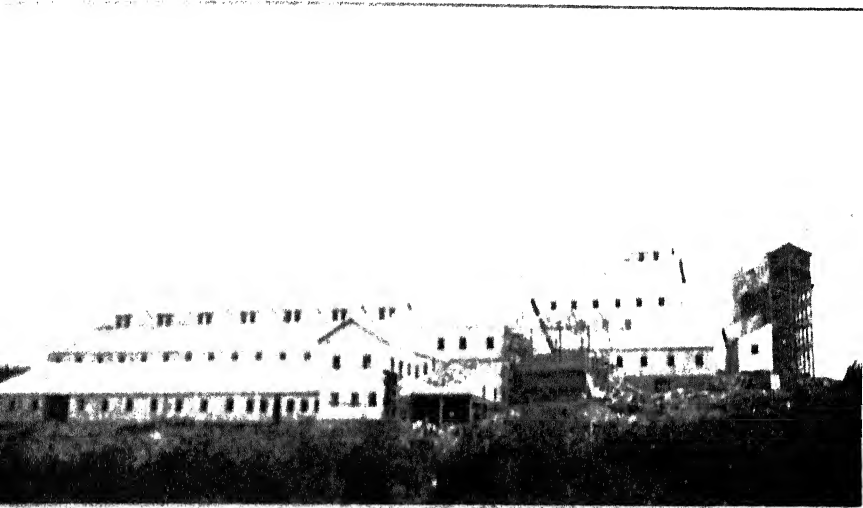
If this is true, then cyanide treatment of the table tailing should be economical in view of the fact that most of the work has already been done on the ore and the additional cost of regrinding plus the cost of chemicals and labor would be more than met by the additional silver recovered. I have already said that the ore, even when finely ground, is difficult to agitate, but this does not conflict with the idea that cyanidation would be economical, because it is conceivable that the fine sand might be leached at a cost which would be less than that of agitating it. I am unable to discover that any exhaustive experiments have been carried out on leaching a concentrate tailing, but I do not know of any good reason why it would not be possible, particularly in those mills where concentration has already been installed. It may be true that a new mill designed for cyaniding the entire product would give the most economical result eventually, but that is no reason why mills now operating as concentrators could not increase their profits by cyaniding the table tailing in some way. The analysis of the ores support this view in so far as showing that the higher grade ores contain most of the elements considered rebellious, while the lower grade ores are comparatively free from them, making cyanidation cheaper on the low-grade minerals. In the accompanying table is presented a statement of the comparative content of the extraordinary elements in Cobalt ores of various grades, *A* representing the high-grade, *B* the medium-grade and *C* the low, or milling-grade ores.

TYPICAL ANALYSES OF COBALT ORES OF DIFFERENT GRADES

	A	B	C
SiO ₂	4.51	2.88	.....
Fe.....	2.34	2.80	7.00
CaO.....	9.05	10.00	3.00
Al ₂ O ₃	1.42	0.87	15.00
MgO.....	6.22	7.13	.....
Ni.....	6.62	8.78	.....
Co.....	7.11	8.42	.....
As.....	29.88	34.48	0.50
Ag. (oz. per ton).....	4786.1	2014.00	71.27

Present Cyaniding Mills.—Four of the Cobalt companies have undertaken cyanidation in some form and degree. These are the Nipissing Mining Co., the Buffalo Mines Co., the Dominion Reduction Co. and

the O'Brien.¹ The Buffalo mill² treats partly by concentration and partly by cyanidation. The ore is broken through crusher and rolls and is partly reground in a high-speed chilean mill, the crushing and grinding being done in water. The slime is separated, thickened in a Dorr thickener and cyanided in Pachuca tanks, the sand being concentrated in water. The tailing is stacked and may be retreated at some future time. Of the sand reground in the chilean mill, only about 5% is slimed, the total quantity of slime cyanided being only 18 to 20% of the total ore crushed. The 200-mesh product is considered as slime and it is largely a granular product, there being very little colloid in it.



NEW LOW GRADE-MILL AT THE NIPISSING.

The mill of the Dominion Reduction Co., formerly known as the Nova Scotia,³ crushes with stamps in cyanide solution. The mill was erected for cyanide treatment alone, small allowance being made for concentration, but having lately entered the custom-milling field it was found necessary to reconstruct the mill, due to the different character of ore to be treated, and this work is now in progress, a system of careful concentration being interposed between the grinding and cyaniding departments. The regrinding in this mill is done in tube mills. Under the reformed system the pulp will be passed through a Callow screen with a 30- or 40-mesh wire cloth, the under size going to sand tables and

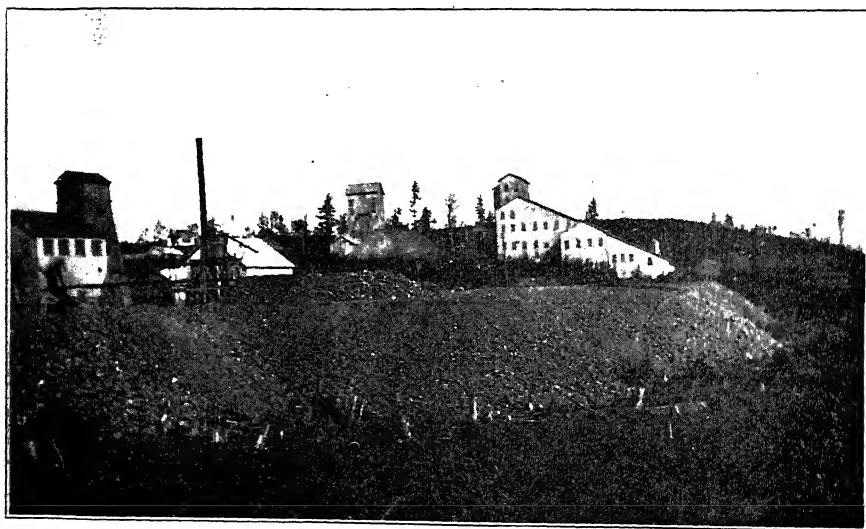
¹ The O'Brien is the property of one man, is not incorporated and is known simply as the O'Brien mine.

² Eng. and Min. Journ., Aug. 3, 1912.

the oversize being reground and returned to the Callow screen. Thus all the pulp will have to pass the screen eventually. From the concen-



MILL OF THE DOMINION REDUCTION CO.



THE O'BRIEN MILL.

trators it will be sent to a modified Dorr classifier where the sand will be drained and taken out, receiving a wash of cyanide solution in the classifier, and will then be discarded. The slime, which carries the greater

part of the valuable content, will be subjected to cyanidation by agitation.

At the O'Brien mill the ore is crushed, jigged and stamped, jigging being done in water and stamping in solution. Reercrushing is done in Hardinge conical mills. Concentration is practised, but to a less extent than usual in the Cobalt mills, the pulp receiving only one passage over the tables. The reground pulp is treated as slime, about 75% of it passing a 200 mesh screen.

New Mill for Low-grade Ores. The Nipissing company has under construction a mill for treating its so-called low-grade ores which assay from 25 to 35 oz. silver per ton. This mill, which is scheduled to begin operations in November of the present year, will be a purely cyaniding one, the only variation being a jigging of the crushed ores. The high-grade rock will be removed on a picking belt, and this, together with the rich jig product, will be treated in the present high-grade mill which will be maintained in operation, as at present, for taking care of the high-grade mine ores and the rich product obtained by the picking and jigging methods. There will be no concentration, no tables or vanners having been included in the design of the mill. There will be 40 stamps of 1500 lb. each and four tube mills, $6\frac{1}{2} \times 20$ ft. Dorr classifiers are to be used for removing the sand which will be tube milled, the entire product being treated by agitation as slime. Zinc-dust precipitation will be used, the standard Merrill triangular press being installed to collect the precipitate. The standard Butters filter will be used for filtering the residue.

The agitation tanks to be used have the flat bottoms and mechanical agitators usually employed by the Butters engineers. The tanks are fitted with decanters and treatment will be by the intermittent or charge system. It is stated that these agitators, while not perfect, will give as good results as can be obtained by the newer forms at costs which are entirely satisfactory in comparison. It is noteworthy that in the face of the more modern forms of agitators, for which higher efficiency and lower costs have been claimed, the older type of agitators are being installed in this modern mill, and also that in spite of the advantages claimed for continuous processes, the charge system will be employed, and all of this sanctioned by a body of engineers which, while not infallible, is fully competent to weigh the advantages of all classes of machinery and make use of the best. The difference of opinion is remarkable and goes to show that neither form of machinery nor method has been able to demonstrate so clearly its superiority as to make it universally accepted. It seems almost certain that one or the other of two forms of machinery, or even of processes, must be the better, the only explanation of the varying opinions being that different ores must give different results when handled by the different processes. Neither is the personal equation to be eliminated, for operators accustomed to a

certain class of machinery and certain methods of working, do not relinquish them with facility, and it is often the most difficult thing in the world to convince an operator that there is some better way of doing things than the particular one he is using.

Primary-crushing Devices.—The persistent use of stamps for reducing rock to various degrees of fineness is an example of the general disinclination to dispense with a form of machinery which has been in use a considerable length of time and which, all things considered, has given a vast amount of satisfactory service. It is difficult to censure the profession for sticking to a device which has served well, but it is nevertheless true that circumstances alter cases, and a machine ought to be considered in the light of the work it is expected to do. When the primary object was to crush ore to a point necessary to liberate its mineral and make it susceptible to amalgamation, then the stamp was a good medium to use. It did the work at one step, and had advantages for amalgamation. It made comparatively little slime, and this was an advantage, particularly in the days when cyanidation was first used and leaching was the accepted practice. The slime was a nuisance and was hard to handle and therefore any machine which produced a minimum of it was considered efficient. With the advent of the total-slime treatment it would seem likely that some other machine might be used which would do the work of reducing ores to a fine state quicker and cheaper, it not being necessary to keep the production of slime down to a minimum.

In spite of this circumstance, the stamp continues to be the standard machine for primary crushing, although there is little doubt but that some other form of machine would be more economical in use. This condition exists all over the mining world and Cobalt is no exception. In preparing ores for cyanidation there is no other object but to crush them to the required point, usually a total slime, in the quickest and cheapest way. Yet most mills use stamps for the purpose and in Cobalt the stamp is used except in one instance, the Buffalo mill. All over the world investigations are being made on this detail and in some cases the stamps have been displaced with distinctly good results. I think that if some trials were made on the Cobalt ores these economies would be manifested there also. The Cobalt ores are hard, but not too hard to be crushed through rolls, and a stage crushing through crushers, rolls and tube mills would seem to indicate the most economical method. It is to be hoped that the system will be given thorough trials on the ores of the camp for such a system would remove many vexations in addition to introducing economies.

Regrinding the Ores.—Tube mills are used for regrinding in the majority of the mills in the Cobalt camp. The Nipissing, new and old mills, the Dominion and the O'Brien mills have installations of them

while the Buffalo, as has already been mentioned, uses a high-speed chilean mill. There is no data at hand for comparing the results of the two forms of machines, but it is probable, on this ore, that the tube mill will give more consistent results. The Hardinge conical mill, as used at the O'Brien mill, has not proved to be altogether satisfactory. The mill is apparently good as a granulator, reducing the rock to a state of medium fine sand with efficiency, but it does not grind fine enough. In this regard the ordinary tube mill is more satisfactory. It is possible to slime the rock in the Hardinge mill, but to do so would reduce its capacity so far as to remove it from consideration as an economical machine. It is possible that the hardness of the ore has something to do with this result for, as has been mentioned, the ore is extremely difficult to slime.

Methods of Agitation. Pachuca tanks are used generally for agitation except in the cases of the Nipissing company, and at the Dominion mill where Trent agitators are at present in use. The Pachuca tanks used in the district are somewhat modified, not conforming exactly with the standard sizes and proportions used in Mexico and in the United States, the difference being that they are not so high in proportion to the diameter. While this reduces the capacity, there is no effect upon the agitation except, perhaps, that it requires less power to accomplish the desired result. The Parral type of agitator is to have a trial in the camp at the new high-grade mill of the Buffalo company, now under construction. This plant, which is, in the main, similar to the corresponding plant of the Nipissing company, contains some details which are considered to be improvements and will be referred to later. In view of the fact that it has been difficult for metallurgists to agree upon the most satisfactory tank for agitation, it will be interesting to have a comparative exhibition of the three classes, Pachuca, Parral and mechanical, at work in the same camp and upon the same material. It is to be hoped that full details of the results will be obtainable.

Use of Chemicals. Lime in some form is used at all the cyanide mills in the camp. At the O'Brien mill the dry lime is added in the batteries and in addition caustic soda is used in the solutions. Caustic soda is not usually considered a good agent to use for securing alkalinity as it tends toward dissolving some compounds which would be better left untouched. There are, however, some cases where its use is justified in spite of its chemical conduct and its cost. The alkalinity at the O'Brien is carried at 3 lb. in terms of NaOH. At the Dominion mill dry lime is added to the ore going to the mill at the rate of about 6 or 7 lb. per ton. The lime is in fine lumps, not powdered, as it is desired to take advantage of the alkalinity developed by the slow solution of the lumps.

At the Buffalo mill lime is added in powdered form to the treatment

tanks at the rate of 7 to 8 lb. per ton of dry ore. The addition of the lime to the treatment tanks in this case is due to the fact that the pulp here meets the cyanide solution for the first time, the preceding operations being carried out in water.

It will be noted that there is a great deal of difference in the manner of using lime in this district, every operator having some special ideas of the most efficient way. Naturally, the lime will be used in the way which seems to be best adapted to each particular ore, but in this case the use of it typifies the state of cyanide practice in the district. It is as yet unsettled, and the best methods for economical results have not yet been definitely determined.

The use of lead salts is varied and spasmodic. There seems to be no definite information as to whether or not they are required and their use, even in the same mill, is not systematized. The general tendency seems to be to dispense with their use. At the Buffalo mill it is claimed that there is no noticeable difference in results whether the lead salts are used or not, and the same is true at the O'Brien mill. Solution analyses at the O'Brien have convinced the operators that the sulphur, which exists in appreciable quantity in solution, is in the form of sulphocyanide. This would indicate that the soluble sulphides, which are undoubtedly first formed, have been transformed by action of the metal elements extracted from the ore and subsequently by the cyanide solutions themselves. If this is true it shows that a portion of the cyanide is removed from its primary object of dissolving silver and is tied up with the sulphur forming a compound which, while having a certain solvent action upon silver, would certainly not be intentionally formed for such purpose. It would apparently be more economical to remove the sulphur definitely from the solution, if possible, leaving the cyanides free to carry out their designed function. It is probably true that the Cobalt ores carry elements which themselves form insoluble sulphides with the dissolved sulphur and remove them, at least partially, from the solutions.

The consumption of cyanide is much the same in all the mills, leaving out, of course, the Nipissing high-grade mill, which is not to be considered with the mills treating large quantities of lower grade ores. From 3 to 6 lb. of KCN per ton of ore treated is the average consumption, when treating ores running from 20 to 35 oz. of silver. At the O'Brien mill the consumption for the year 1911 was 5 lb. KCN per ton of ore treated, while for the present year the records up to date show a consumption of 3.8 lb. per ton. At the Buffalo and Dominion mills the consumption will average about the same and at the Nipissing high-grade mill the figures are reserved from publication, but the consumption is probably high.

Metal Recoveries.—The percentage recovery of silver, as at

a great deal in the different mills of the camp. From 80 to 90% is about the saving that is attained by cyanidation, except in the Nipissing mill. In the latter a saving is made by amalgamation of 97% and in the subsequent cyanidation a small additional saving is made. The head content of silver at this mill runs about 2500 oz. silver and the tailing is said to be as low as 20 to 30 oz. per ton. The extraordinary percentage of extraction is, of course, accounted for by the richness of the ore treated. At the O'Brien mill concentration and cyanidation reduce 20-oz. heads to a tailing which averages 1 to 1.5 oz. per ton in silver. At the Buffalo mill where only the slime is cyanided the extraction on the material is from 80 to 85%, but this is by the cyanide treatment alone and no comparisons can be made between this result and the results obtained at the other mills in the district. At the Dominion mill no extraction results are obtainable at this time due to the fact that a change of method is being made, and while the mill is actually in operation, the newer method is not yet fully installed and no statement can be made.

It is generally conceded that the percentage extraction depends largely upon the fineness to which the ore is ground, the finer grinding giving a better recovery of metal than the coarser. This is to be expected in view of the density of the ore which does not permit penetration of the cyanide solutions into the ore particles and requires extreme subdivision in order to expose the maximum amount of the silver to the action of solutions.

Temperature has also a great effect upon extractions. In the winter season the cold solutions lower extractions to a large extent and it is often necessary to warm the solutions in order to obtain normal results. At the Buffalo mill steam coils are placed in the treatment tanks in order to bring the solutions up to normal efficiency. In this case the warming is particularly necessary, for there is a constant introduction of cold water into the treatment circulation from the grinding department. At other mills where the circulation is entirely cyanide solution, a thorough heating of the mill during the winter season suffices to keep the solutions active.

Precipitation Systems.—The precipitant most favored is zinc dust which will ultimately be used in practically all the mills. At the Buffalo mill the precipitation is at present by zinc shavings, three wooden boxes of the ordinary type being used. At the Dominion mill zinc dust is used and the regular Merrill triangular filter press is installed for collecting the precipitate. The consumption is in this case $1\frac{1}{2}$ of zinc to one of silver precipitated, by weight. At the new mill of the Nipissing company the same process will be used and the resultant precipitate will be sent to the refinery of the high-grade mill which has already been described.

At the O'Brien mill the process is the same mechanically, but zinc dust is replaced by aluminum powder. It is stated that the aluminum powder will precipitate three times its weight of silver and has a lesser

fouling effect upon the solutions. The claim is also made that the resulting precipitate may be melted in the ordinary oil-fired tilting furnace without any flux, giving a bullion of high purity. The cost of the aluminum dust, which is 32c. per lb., compared with the cost of zinc, about 7c. per lb., does not indicate any appreciable economy in the use of aluminum even with its increased efficiency, unless there are some advantages not clearly understood. It is probable that further experiments will be made on the use of this material so that some definite facts may become known and comparisons established with the results accomplished with zinc dust.

Vacuum Filtration.—Vacuum filters are at present in use in all the mills, the Butters and Moore types being the ones preferred. At the Nipissing, both the high-grade mill and the new low-grade mill are equipped with Butters filters of the standard type. The Dominion mill has a Moore filter as has also the O'Brien mill. In all these mills a high efficiency is claimed for the filters in washing out dissolved silver, but from the looks of the installations it is rather difficult to understand how high efficiencies can be claimed on any of them. The great weight of the pulp and its granular condition make it necessary that the filter tank be equipped with air lifts in order to keep the solids in suspension, and a rather violent action is necessary to do the work. The filters cannot be operated at all without the air lifts as the heavy solids would settle immediately making operation impossible. From the nature of the ore and the condition of the filters in the Cobalt camp I should think that pressure filters would be likely to give much better results than those operated on the vacuum system. Pressure systems, like the Merrill, would take a definite quantity of pulp and make a fairly homogeneous cake at once, and would tend toward a condition which would facilitate proper washing of the cake. With the vacuum filters some segregation must naturally take place, and a filter cake which is not homogeneous cannot be washed perfectly. The pressure filter would, in my opinion, be a decided improvement over vacuum systems in the Cobalt camp, due to the weight and granular character of the solids in the pulp treated.

Cost of Operations.—The cost of treatment in the Cobalt camp is not obtainable in the majority of cases, due to the fact that some of the mills are treating custom ores and consequently do not care to make public that essential part of the business. It may be stated that the treatment of the mill or low-grade ores costs from \$2.50 to \$4.50 per ton. This seems to be a rather wide variation of cost on ore which is practically identical and which is treated on more or less the same scale. The variation is wide indeed, but, as has already been mentioned, there are so many different ideas and so many different methods in use in the camp that there is bound to be a variation in cost. Probably the cost for cyanidation is less at the Buffalo mill because of the small extent and simplicity

treatment, most of the charge for reduction being made against the cyanation department. At the Buffalo, the cost may be said to be the lower figure given, while at the other two mills costs varying at the higher figure may be taken as representing the average. At present, as no costs at all are divulged, but the report of the company for 1911 shows that the cost per ounce of silver at the high-grade mill is 1.14c. At this rate, considering the average ore treated as 2500 oz. per ton, the cost per ton of treatment would be \$28.50. It seems to be a fair average figure for an operation of this sort. It is likely that the majority of this cost consists of cyanide consumed and lost, the other charges being of comparatively less importance. The cost of material at Cobalt is about as follows: Cyanide (KCN usually used) 15c. per lb.; zinc dust (90% metallic zinc) 6.5 to 7c. per lb. (imported) \$20 per ton. Power varies somewhat in cost, municipal contracts being made on a basis of \$50 per horsepower-year, private contracts now being made are at the rate of one cent per kilowatt-hour. I understand, to a change in the policy of the power companies to serve the district. The cost items in general are not excessive and could be done at reasonable cost.

Buffalo High-grade Mill. The Buffalo company is erecting a small plant to treat its high-grade mine product and concentrates, similar to the

MATERIAL FOR REFINING FURNACE AT BUFFALO MINES, LTD.

Material	Dimensions	Quantity
.....	.....	4000
.....	$4\frac{1}{2} \times 9 \times 2\frac{1}{2}$ in.	1200
.....	$4\frac{1}{2}$ and $4 \times 9 \times 3$	375
"A".....	$4\frac{1}{2}$ and $5\frac{1}{8} \times 9 \times 2\frac{1}{2}$	14
"AA".....	$4\frac{1}{2}$ and $5\frac{1}{8} \times 9 \times 2\frac{1}{2} \times 3\frac{1}{2}$	1
"B".....	$2\frac{1}{2}$ and $3\frac{1}{2} \times 9 \times 4\frac{1}{2}$	12
"C".....	.....	26
"CC".....	.....	2
"D".....	.....	28
"DD".....	.....	2
"E".....	.....	2
"EE".....	.....	2
.....	3 in. \times 5 ft. 6 in.	6
.....	4 in. \times 6 ft. 6 in.	12
.....	3 in. \times 3 in. \times 8 ft. 6 in.	2
.....	3 in. \times 3 in. \times 6 ft. 3 in.	2
.....	$\frac{3}{4}$ in. \times 8 ft.	8
.....	$\frac{3}{4}$ in. \times 10 ft. 3 in.	4
.....	$\frac{3}{4}$ in. \times 4 in. \times 6 in.	12
.....	.....	2
.....	.....	10
.....	3 ft. 8 in. \times 5 ft. 11 $\frac{1}{2}$ in. \times 14 in. high	.....

installation at the Nipissing. The differences are that the tube mill is larger, $5\frac{1}{2} \times 22$ ft.; the agitation will be performed in tanks of the Par-ral type; a concentrator with a copper top will be installed over which the pulp will be passed after amalgamation in order to recover any floured quicksilver, and filtration will be performed in a large Perrin plate-and-frame filter press having a capacity of about 20 tons of dry solids. Refining will be performed as at the Nipissing, in a reverberatory furnace, which by courtesy of H. G. S. Anderson, superintendent of the Buffalo mill I am able to present in detail in the accompanying drawing. The system seems to be well adapted for this class of work and it is not impossible that its use might be profitably extended to other cyaniding installations.

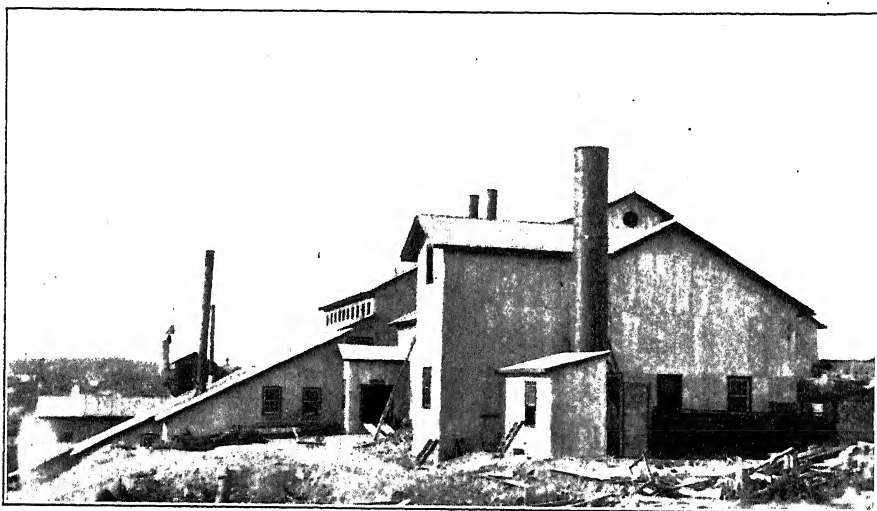
Future Development.—The details of cyanidation of the Cobalt ores have not yet been definitely settled and the metallurgy is in a state of evolution such that little is really known. There have been few points definitely settled and I expect to see most of the mills make radical changes before settling down to routine work. Many methods are in use which do not seem altogether suited to the conditions and it is likely that these will be gradually changed as some systems prove their superiority. Results obtained in extraction are not yet reliable, as most of them are based on estimates, and the same is true of costs, which are so varied and indefinite as to be not suitable for comparison. There are many skillful metallurgists at work in the district who may be relied upon to work out the processes in time and I have no doubt that the district will reach a state of settled and satisfactory cyanidation after time has been given to allow the problems, which are many and difficult, to be worked out.

CHAPTER II

NIPISSING HIGH-GRADE MILL, COBALT

The high-grade ores of the Cobalt district consist mainly of the arsenides of cobalt and nickel in a calcite gangue with a large quantity of silver in the metallic state. A typical ore carries 10% silver, 9% cobalt, 6% nickel and 39% arsenic; the rest is lime, silica and smaller amounts of antimony, iron, sulphur, tellurium, etc.

Ore Character.—The complex nature of the ore and its high content in arsenic make it an undesirable ore for the ordinary custom smelter,



NIPISSING HIGH-GRADE MILL.

who is compelled to charge a high price for its reduction. The general practice is to smelt in a blast furnace where a large part of the silver is recovered at once as base bullion; the resulting speiss is roasted and treated in the wet way for the recovery of the cobalt, nickel and the rest of the silver. This process is slow; the necessary plant costs several hundred thousand dollars, and a large working capital must be available to carry on the business.

Another serious problem in shipping to a smelter was the difficulty in obtaining a fair sample of the ore. This is always a tender point when a mine is marketing ore, but when the ore carries several thousand ounces of

silver per ton and the silver occurs in the metallic state, ranging in size from the smallest particles up to nuggets the size of one's hand, the difficulty of sampling is enormously increased.

Great improvement, however, has been made in this part of the marketing by the building of the Campbell & Deyell custom sampling works at Cobalt, where the ore is crushed in a ball mill fitted with 10- to 20-mesh screens. All metallies coarser than this mesh remain in the mill and are subsequently removed and melted down to bullion. The pulp can then be sampled with a reasonable degree of accuracy.

The marketing expense is made up of smelter deduction, treatment, freight, assaying, representation at smelter, etc. On 23 carloads of ore averaging 2560 oz. per ton, the marketing expense was 5.57% of the gross value (with silver at 60 c. per oz.) or \$83.55 per ton. In addition to the above direct charge, there is a loss of interest from the date of shipment to the date of payment, which averages 65 days on shipments to Canadian smelters, and all ore is settled for on the commercial assay, which is about 1% lower than the actual assay on this grade of ore.

As the largest producer in the district, the Nipissing Mining Co., Ltd., had been trying for several years to find a simple process by which its high-grade ores could be treated at the mine without going to the large expense of building the usual smelter. To this end a great many processes had been investigated and one small experimental plant was built; the trouble with most of the processes is the complication of the operations and the consequent tying up of a large amount of money.

An Original Process.—It remained to Charles Butters and G. H. Clevenger, finally to work out a process which promised to be so simple and effective that the Nipissing company decided to build the necessary plant at once. James Johnston designed and constructed the plant which went into operation February, 1911, and has run successfully ever since.

The high-grade ore from the picking tables is delivered to the sampling plant at the top of the mill where it is put through a 9×15-in. Blake crusher and elevated to a steel receiving bin. From this it is fed automatically into a No. 3 6-ft. Krupp ball mill carrying 1000 lb. of steel balls and fitted with 20-mesh screens. The metallies or silver nuggets which will not pass the screen are removed periodically by taking off a screen, and are melted down in the refinery. From the ball mill the pulp is delivered by a spiral feed to a Vezin sampler and elevated to two 60-ton steel storage tanks, from which it is drawn as needed for treatment in the mill.

The main operation consists of amalgamating the silver in a 5% cyanide solution while the 20-mesh material is being ground in a tube mill. The mill used is a Krupp mill 3 ft. 11 in. in diameter and 19 ft. 8 in. long,

fitted with silex-liners and run at 37 r.p.m. The weight of ore per charge depends somewhat on the silver content, but with 2500-oz. ore the ordinary tube-mill charge is 6500 lb. of ore; 8500 lb. of mercury; 3800 lb. of cyanide solution, and six tons of pebbles.

The materials are charged through a manhole on the top of the mill, and after the cover has been replaced the mill is revolved for $9\frac{1}{2}$ hr., when 99% of the pulp will pass a 200-mesh screen. This fine grinding is necessary to liberate the fine particles of silver and permit of complete amalgamation. A screen analysis of the final tailing shows that the coarser particles are much richer than the slime; this is also shown by the accompanying screen tests on ore crushed through a 10-mesh screen.

It was found advantageous to have a certain quantity of silver go into solution in the cyanide, and to this end more air had to be supplied to the charge.

Each gudgeon of the mill is fitted with a stuffing box through which passes a heavy cast-iron pipe, four inches outside diameter, with a $1\frac{1}{2}$ -in. hole through the center. The casting is held stationary by bolts to

GRADING ANALYSIS OF NIPISSING ORE CRUSHED THROUGH 10-MESH

Mesh	Percentage by weight	Silver oz. per ton
+ 20.....	12.7	6837
+ 40.....	26.2	3375
+ 60.....	11.6	2330
+ 80.....	6.3	1954
+ 100.....	6.3	1654
+ 120.....	2.7	1348
+ 150.....	1.3	1182
+ 200.....	3.8	1202
- 200.....	29.1	706

the concrete foundation, and the mill revolves about the pipe. Compressed air under 25 lb. pressure is introduced through one of the hollow castings. At the outlet end there is a right-angle turn in the hollow casting just inside the mill and the upper end reaches to within $\frac{1}{2}$ in. of the lining. The heavy cast-iron elbow, therefore, remains stationary, the inside leg stands vertical, and the upper end remains above the level of the charge at all times, allowing the compressed air to escape while the mill is in motion. The casting is heavy enough to withstand the battering of the pebbles falling against it. This arrangement allows the mill to be filled well above the center with a consequent decrease in the power used, but it is found that the best results are obtained by filling the mill to a point two inches above the center.

Handling the Tube-mill Product.—At the end of the grinding period the three manhole covers are replaced by coarse screens and the mill is

turned over; the charge falls into a sheet-iron hopper which delivers it into an all-iron settler, eight feet in diameter, fitted with wooden shoes. The tube mill is then washed out twice by revolving it with a ton of solution and 1500 lb. of mercury. These washes are added to the charge and the settler filled with solution; the charge is kept in agitation by the muller while the amalgam is drawn off into an iron clean-up pan, and from there into canvas amalgam filters, of which there are 24, each holding 400 lb. of amalgam. The pulp is gradually run out of the settler by drawing the top plug, the balance of the charge being washed twice with solution. When the flow of amalgam has ceased, the mercury, as it drains out of the canvas filters, is pumped back to the settler to wash out any remaining amalgam. The bottom plug is finally drawn and the balance of the pulp discharged. It requires two hours to dump the charge and get the amalgam into the filters.

It was soon found that the amalgam must be kept exceedingly thin, otherwise it would stick in the tube mill and cake under the muller of the settler; hence the mercury used is 15 times the weight of the silver in the ore. After draining in the sacks, the amalgam still carries 78% mercury. The remarkable part about the whole process is that 97% to 98% of the total silver in the ore yields to amalgamation in the tube mill. An ore assaying 2500 oz. per ton is reduced to 50 to 75 oz. per ton when it leaves the settler.

The Role of Cyanide. The cyanide treatment of the pulp which follows is comparatively unimportant as it deals only with six or seven tons of 50-oz. ore daily. There are four 16×7-ft. wooden tanks for the collection and treatment of the pulp, and the necessary tanks for storage of solution and water. A charge for agitation is made up of four tube-mill charges or 13 tons of dry pulp. Five pounds of lime per dry ton of pulp are added and the charge is agitated for 36 hr.; the tanks are fitted with mechanical agitators, and the pulp is circulated through a pump as well. The cyanide strength is 0.75 per cent.

After settling, the solution is decanted, and the pulp, having a specific gravity of 2, is run to a Butters filter of 10 leaves. The specific gravity of the ore is 6, and to avoid the settling of the pulp in the bottom of the filter box while the cake is forming, the charge is kept in circulation by an air lift drawing out of the bottom of the box and delivering at the top. The cake is washed 2 1/2 hr. with weak solution and then discharged. The arsenides of cobalt and nickel go through the process practically unchanged; the residue for the first seven months of this year contained 9% cobalt and 4.5% nickel.

Analysis of Ore.—The complex nature of this residue is shown by the following analysis by Johnson & Sons on some of last year's product: Nickel, 9.72%; cobalt, 5.85%; iron, 2.58%; antimony, 3.80%; bis-

muth, 0.09%; copper, 0.06%; tellurium, 1.39%; arsenic, 29.50%; sulphur, 1.59%; silica, 11.44%; lime, 8.63%; magnesia, 2.91%; carbonic acid, 13.55%; combined water, 5.74%; mercury, alkali, oxygen, gold and silver, traces of zinc, tin and manganese, 3.15%. Determinations of mercury consumption indicated the presence of mercury in the ore itself. Investigation along this line showed that the ordinary high-grade ore of the district usually carries from two to five pounds of mercury per ton of ore, depending upon the amount of metallics contained. Tests were then made on the metallics alone; 21 samples of metallics taken from various Nipissing veins and from three other mines, showed mercury in every case; the result varied from eight to 95 lb. mercury per ton of metallics and averaged 35 pounds.

The presence of mercury in the metallics was proved on a large scale when the refinery was built; the first charge melted down in the reverberatory when the furnace and flues were clean, was a ton of metallics. A small bottle full of mercury was taken from the condenser and globules of mercury could be plainly seen through the flue dust.

Method of Precipitation.—There are two zinc precipitation boxes, one for strong and one for weak solution. The precipitate from both boxes goes to an 18-in. Johnson filter press with 12 frames; the press holds 500 lb. of precipitate which assays 15,000 oz. silver per ton. The product of the cyanide plant amounts to 8000 to 10,000 oz. silver per month.

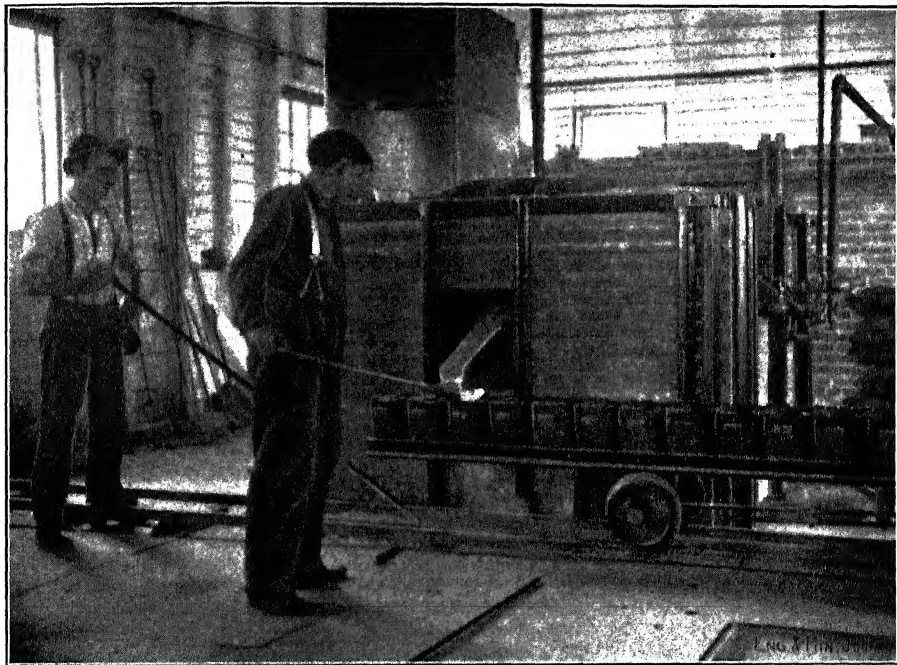
The solution going to the zinc box carries 14 oz. silver per ton, 0.028% mercury and 0.6% zinc. By passing through the box the mercury in solution is reduced to 0.015%, so it is necessary to retort the precipitate to recover the mercury. As no solution is thrown away, it has become very foul; after passing through the zinc box it runs to a storage tank in the bottom of which a precipitate collects. An analysis of this precipitate follows: Silver, 0.394%; mercury, 2.51%; antimony, 3.30%; sulphur, 16.13%; arsenic, 32.64%; silica, 5.362%; zinc, 2.257%; iron, 5.04%; nickel, 9.06%; cobalt, 7.03%; lime, 9.24%; carbon dioxide, 7.259%; manganese, trace.

The sacks of amalgam are hoisted into a car with a cast-iron body, weighed and taken to the refinery which adjoins, but is separate from the mill building. There are six 14×60-in. retorts mounted in batteries of two. They are fired by oil, and the waste gases are conducted through a condenser before discharging them; this is to catch any mercury which might get into the flue on account of a cracked retort.

The retorts are filled three-quarters full of amalgam, fired for nine hours, and allowed to cool for six hours. The resulting sponge and mercury are weighed and compared with the weight of amalgam put in the retort; a cracked retort will sometimes be detected by the loss in

weight when it has not been noticed by the man in charge. The sponge is 79% silver; the impurities are mainly arsenic, cobalt, nickel, antimony and bismuth.

The average life of a retort is 34 charges. As soon as the slightest crack appears the retort must be discarded at once. Occasionally a retort will break on the first firing, and retorts have been received which would not hold mercury when cold. Various grades of iron have been tried but the makers have not succeeded in turning out a cast-iron retort

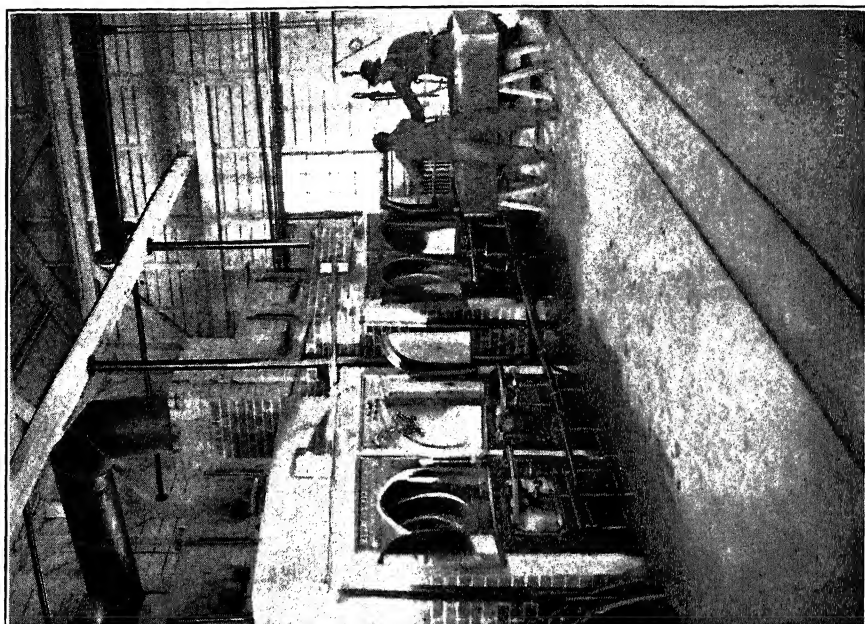


RUNNING THE SILVER FROM FURNACE INTO MOLDS.

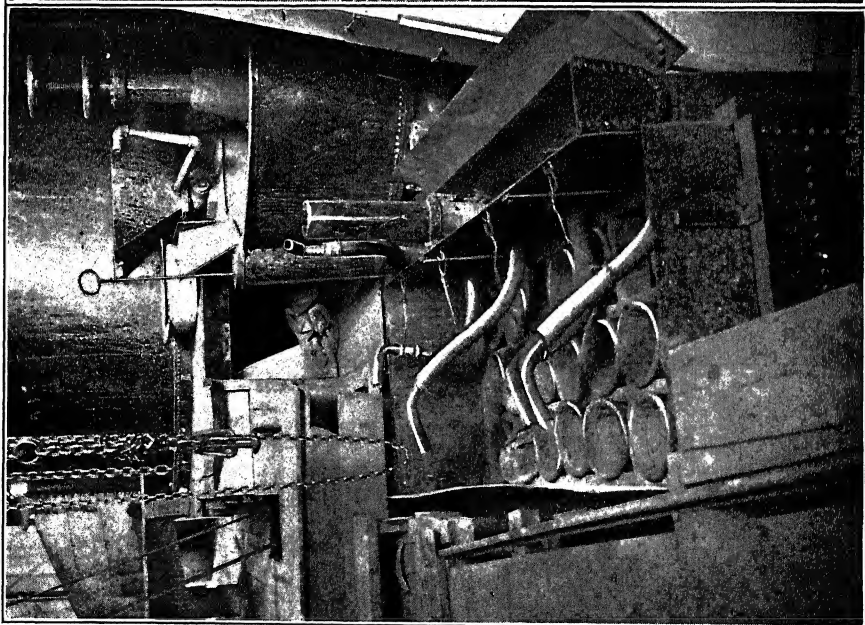
which will stand up to the hard and continuous work required. A soft gray iron, low in phosphorus, gives the best results.

Recently a cast-steel retort was installed; it is still in good condition after having been fired 82 times. A specially made wrought-iron retort with sides $3/8$ in. thick is now on order; this will be slipped into a cast-iron cylinder which will take the weight of the charge and bear the brunt of the firing.

Melting of the Sponge.—The sponge from the retorts is melted down in a reverberatory furnace in charges containing 28,000 oz. of refined silver. The hearth is stationary and is made of brick contained in an iron pan, 5 ft. \times 5 ft. 6 in., supported on rails. Heat is supplied by two



CHARGING THE RETORTS.



CLEANUP PAN AND AMALGAM SACKS.

oil burners; the waste gases pass first through a series of dust chambers, then through two iron pipes 3×27 ft. and to a fan which exhausts into the stack. Sprays of water are introduced into the last dust chamber and into the first iron pipe, the object being to cool the gases and condense any mercury that is driven off in melting the sponge, or that comes from a leaky retort.

As soon as the charge in the reverberatory is melted, air under 15 lb. pressure is blown on the surface through two iron pipes introduced at the back of the furnace. The oxides of cobalt, nickel and the other impurities rapidly rise to the surface and are scraped off through the charging door. No flux of any kind is added. The air blown on the surface of the metal has been heated by carrying the pipe through the dust chambers; this materially shortens the operation which usually takes 18 to 20 hr. After the surface of the metal has become mirror-like it must still be blown several hours to expel the last traces of impurities.

Dip samples are taken and when the bath is 999 fine the air is shut off and the metal is covered with charcoal to absorb the included oxygen and thus avoid sprouting of the bars. The furnace is tapped through the side; the charge fills 25 molds which are run along under the spout on a car.

The first hearth was made of common firebrick; it lasted five months during which time 1,860,000 oz. were refined. The present hearth made of magnesite brick is still in good repair after nine months' use and has turned out to date 3,236,000 fine ounces.

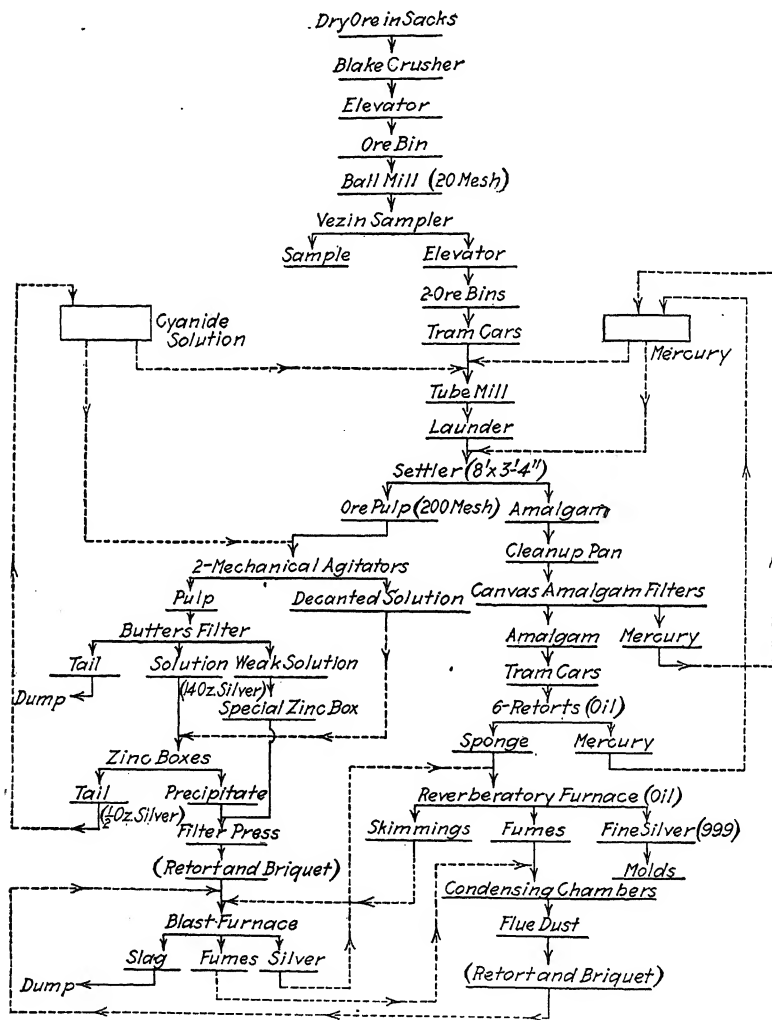
Smelting the Precipitate.—For the purpose of working up the skimming from the melting furnace, the flue dust and the zinc precipitate from the cyanide plant, a 20-in. round water-jacketed blast furnace was installed. The jacket is hung from the feed floor to allow removal of the curb. The flue is connected with the dust chambers. Before being charged to the blast furnace the flue dust and precipitate are retorted, then mixed with sugar water, briquetted and dried.

The skimming assays about 15,000 oz. silver per ton, the flue dust 700 oz., and the precipitate 15,000 to 18,000 oz. The charge is calculated according to the material to be put through; some of the mixtures used are as follows: Charge 1: 250 lb. of skimming; 300 lb. of slag; 100 lb. of coke. Charge 2: 100 lb. of skimming; 100 lb. of flue dust; 300 lb. of slag; 40 lb. of iron ore; 100 lb. of coke. Charge 3: 10 lb. of flue dust; 20 lb. of precipitate; 30 lb. of slag; 25 lb. of iron ore; 15 lb. of limestone. These charges gave a slag carrying from five to 11 oz. of silver per ton.

The charge being so rich in silver no lead is necessary. As soon as the crucible is half full of bullion the metal is drawn off into molds. A small amount of speiss is also formed. The bullion runs 800 fine and is melted

down in the reverberatory with the sponge. It is only necessary to run the blast furnace one day in every 10, to clean up all the by-products.

The only product marketed is fine silver. It is shipped direct to London and sold at the daily quotation without refining charge. Ship-



FLOW SHEET OF HIGH-GRADE MILL.

ments this year have amounted to 370,000 oz. per month. The bullion carries 0.0043% gold, equal to about \$1 per 1200-oz. bar. The total cost of the plant was \$67,757, which includes sampler, mill and refinery.

CHAPTER III

NIPISSING HIGH-GRADE MILL, COBALT Concluded

The works of the Nipissing Mining Co., Ltd., is situated on the east side of Cobalt Lake, nearly opposite the town of Cobalt in Ontario. The company has had to solve a metallurgical problem that presented unusual features, and has resulted in a unique plant for milling the high-grade silver ore.

Ore Character.—The ore to be treated contains a large variety of elements, among which may be mentioned about 40% arsenic, 6% cobalt, 6 to 7% nickel and varying percentages of antimony, manganese and a large amount of sulphur.

In addition to the elements already mentioned, the ore is extremely rich in silver, being indeed one which is not usually considered in any sense a milling ore. It carries from 2000 to 4000 oz. per ton, an average of 2500 oz. silver per ton being usual over long periods of time.

The suggestion of treating an ore of this grade, running nearly 80 kg. per ton in silver, by any milling process would be treated warily by most metallurgists, the difficulties certain to be encountered being more than most would care to face. The first impulse would be to ship this rich ore to a smeltery in the confidence that a nearly total extraction might be obtained at a cost lower than could be hoped for under milling conditions.

After careful consideration, however, the Nipissing Mining Co., Ltd., of which R. B. Watson is manager, came to the conclusion that the highest economy lay in treating the ore on the ground, making only one product—bullion. The problems of metallurgy were placed in the hands of Charles Butters, consulting metallurgist for the company, assisted by G. H. Clevenger and James Johnston, who built the mill and has since been in charge of it. The result is the so-called high-grade mill.

Ore of this character, containing as it does, pieces of rock of varying grade from nothing up to native silver, cannot be satisfactorily sampled in a coarse state. At the Nipissing mill the sampling is done after the ball mill has crushed the entire material to pass a 20-mesh screen, when it can be done with accuracy

As all the breaking and grinding up to this point is performed on the dry ore, there is naturally some dust formed, and it follows from the grade of the material that this dust contains a valuable quantity of silver. In

are led to places where it can best be collected, the fan delivering into a baghouse from which point it may be returned to the treatment system.

The fine ore is taken to a platform over a 4×20-ft. Krupp tube mill. This portion of the metallurgy is unique and somewhat astonishing.

Extraordinary Amalgamation.—The tube mill has its axial entrances sealed up except for a small compressed-air pipe which enters it at one end and a corresponding air exit at the other end. The mill has the usual manholes in the tube, but these are seldom used. Instead there are three handholes with the usual covers equally spaced over the length of the mill on the same horizontal line. Through these holes the mill is charged and discharged, the larger holes being necessary only when relining or repairing inside the tube

Here, then, is a tube mill used as an amalgamating barrel, but under conditions which were probably never before sought for amalgamating purposes. The combination of an extremely high cyanide solution, a complex ore which contains all sorts of elements, and mercury all ground violently in a pebble mill, would seem to induce conditions quite the reverse of satisfactory. The natural expectation is that the mercury would become floured and that a large loss of it would be incurred. Particularly would this seem to be the case after the absorption of a quantity of silver would have resulted in the formation of amalgam with a tendency toward granulation, an ideal condition to be thoroughly "sickened" by the foreign elements in the ore.

It is stated that this does not occur, which must be largely due to the strong cyanide solution keeping the mercury clean and allowing the fine particles to coalesce without hindrance from a coating of foreign substances. The heat formed in the mill may also have some effect in a beneficial way by tending to keep the mercury fluid and active. There is a great deal of heat generated in the mill, in fact steam would be formed were it not for the stream of compressed air which enters one axis of the mill and is discharged through a standing pipe at the other. This keeps down the temperature, though even with this cooling assistance the temperature of the mixture after completion of the agitation period is about 90 degrees.

Use of Chemicals.—It is noteworthy that neither lime nor lead salts are used during this process, and that after the agitation is complete, there is still sufficient cyanide to carry on the subsequent operations without further addition. The amount originally added to the tube mill is sufficient to produce a very strong solution, which is capable of partially outlasting the destroying effect encountered within the mill.

The agitation is continued for nine hours, after which time 97% of the contained silver has been extracted from the ore. The tube mill

makes 37 r.p.m. and, contrary to the general practice of the day, is lined with silex brick.

Power.—The charge which is put into the mill fills it more than half full; there is little space left after putting in the total charge. This results in balancing the mill so that during the agitation process it requires only about 17 hp. to keep it in motion. When the mill is emptied of the charge and contains only the pebbles, it requires nearly 40 hp. to move it.

Cyaniding the Pulp. The agitating tanks are of the flat-bottomed type, having mechanical agitating appliances. These consist of a vertical shaft, to which arms are fixed, reaching nearly to the periphery of the tank. The vertical shaft is moved at a rate of 30 r.p.m., by means of crown wheel and pinion gearing. The high speed of these agitators is worthy of note, the necessity for it being found in the high specific gravity of the ore, which is almost equal to an ordinary concentrate. Besides, the ore is so hard that only a small portion of it ever becomes a true slime, but remains in a granular form and has that tendency to settle characteristic of such material. The high speed is necessary to keep the solids in suspension

The striking feature of the cyanidation of the pulp is not in the method followed, which is the usual one, but in the fact that it is carried out in solutions, which must necessarily be in a state which is not usually regarded as being efficient for cyanidation. A consideration of what these solutions must contain, coming, as they do, from intimate contact with the conglomeration of elements found in the tube mill, will indicate that they must be more or less foul and in a condition which is not favorable to maximum efficiency. This matter will be referred to later

Precipitating the Solution Content.—The solutions are precipitated by means of zinc shavings in a box of the usual design, which has eight compartments, each compartment having room for about six cubic feet of zinc. The shaving used is rather coarser than that usually used, resembling a stout wire, the width of the shaving being nearly equal to the thickness of the sheet from which it is cut

The refinery department presents some unusual features. There are six retorts of the horizontal tubular type set in brick, each retort measuring 14×60 in. These retorts are heated by oil burners, thus making the operation simpler, cleaner and easier than when wood or coal is used. The oil burners are capable of generating a degree of heat which is entirely satisfactory and the operation is not troublesome

The precipitate from the cyanide department is mixed with a borax-soda flux of the composition usual for precipitate, briquetted and melted in a small blast furnace, together with the skimmings from the reverberatory furnace and other cleanings of value. This blast-furnace system of

melting is not new, having been practised before in different places. It is a good system when properly followed, but is not to be promiscuously recommended

From the standpoint of cyanidation there are several points about this metallurgy which attract attention. The first one is the use of a solution high in cyanide content for the amalgamation process. Of course, the intention is to use the cyanide entirely as an aid in amalgamation, there being not the least effort to put silver into solution during this stage. Nevertheless a portion of the silver must be dissolved along with a large number of other elements. The wonder is that there is any available cyanide left at all after the amalgamation period is over.

Considerations of Theory.—A question which is naturally suggested is whether the mercury is dissolved to any extent, and if so, what becomes of it. Some authorities claim that mercury in the native state is not dissolved by cyanide solutions while others take the opposite view. I am inclined to believe that it depends a great deal upon conditions. A volume of mercury in quiet contact with cyanide solution will probably not dissolve to any great extent, but mercury in a finely divided state and amalgamated with other metals will be likely to go into solution. Such a finely divided and amalgamated state is certain to exist inside the tube mill during the amalgamation period when it is subjected to the grinding action of the pebbles, and it seems quite likely that a portion of the mercury would be dissolved. In any case it is well known that some compounds of mercury are readily soluble in ordinary cyanide solutions and it is not at all unlikely that some such compounds are formed during the amalgamation period, so that it seems reasonable to assume that there would be some mercury in the solution.

If this is agreed upon it is easy to see why lead salts are not necessary in subsequent cyanide treatment, for the mercury would decompose the soluble sulphides precipitating HgS . In addition, the double cyanide of mercury, $\text{K}_2\text{Hg}(\text{CN})_4$, formed is an active solvent of silver and might assist in recovering additional amounts of it.

While it has been stated that no lime is added to the tube mill during the amalgamation period, the fact that mill solutions are used makes it necessary that lime in solution be present, at least at the initial period, though it is conceivable that it would be destroyed soon after agitation had been started.

In addition to the mercury there are elements in the ore, such as nickel, cobalt, manganese, sulphur, and arsenic, which would enter solution. This presents an opportunity for all sorts of chemical reactions to take place which would be exceedingly difficult to follow. The well known affinity of mercury for sulphur would account for its removal from solution and it seems likely that the other elements would be precipitated

in some form at some stage of treatment. It is only reasonable to expect that the solution of the metallic elements as cyanides and their consequent transformation into other forms would act as reducers to the solution, robbing them of some of the oxygen which would otherwise be available and retarding the dissolution of silver.

Character of Solutions.—A peculiarity of the solutions used in this treatment is that they contain quantities of a brownish-black precipitate floating in them. This precipitate is not noticeable until the solutions enter the precipitation box where so much of it is liberated that it obscures the zinc. In spite of this condition, which would apparently be fatal to good precipitation, the results are good, as shown by the solution assays already given, and the action in the zinc box is lively and normal, shown by the evolution of gas.

The floating precipitate is light in weight and does not remain on the zinc to any large extent, but does settle in the sump tank, an analysis of it showing that it contains practically all the elements mentioned as existing in the ore, together with portions of zinc and mercury.

The zinc in the zinc box does not show much effect of mercury, which has the property of amalgamating with the zinc and causing it to break up into a soft mass of short, amalgamated zinc. There may be some slight indication of it, but not enough to account for the presence of any considerable quantity of mercury in the solution

CHAPTER IV

THE HOLLINGER MILL, PORCUPINE

The plant of the Hollinger Gold Mines, Ltd., is situated east of Miller Lake, near the town of Timmins in the Porcupine district of Ontario, Canada. The mill occupies a site on the side of a hill in proximity to the main shaft from which the ore is hoisted from the mine. The ore is broken to a size appropriate for stamp milling at the shaft head and is then conveyed by means of an inclined belt conveyor to the mill bins, where it begins the process of reduction. The accompanying engraving of an east view of the mill shows the conveyor which carries the broken ore to the mill bins.

Ore Classification.—The ore, in which gold is the valuable constituent, is comparatively soft and is easily crushed, the crushing and grinding



THE HOLLINGER MINE AND MILL.

machinery having a high rate of efficiency, as will be shown. The mill run consists of about two-thirds sericitic schist and about one-third quartz, all the rock being highly schistose and for this reason easily crushed and ground. While a good proportion of slime is formed, there is also a large proportion of fine sand in the product which passes a 200-mesh screen. Thus a product for treatment is formed which is largely granular in character and which presents the difficulties usually encountered in a pulp of this character. The mineral is heavy, the dry slime having a specific gravity of about 2.85. A pulp of this character always is trouble-

some to handle on account of its tendency to settle at every opportunity, and the machinery for handling it has to be designed particularly with the idea of obviating, as far as possible, every chance for the heavy, granular solids to settle and give trouble in treatment.

The ore from the mine is first passed through a No. 7 Kennedy gyratory crusher, after which it goes through a trommel having 2½-in. openings, the undersize going directly to the 20-in. inclined belt conveyor, which carries it to the mill, while the oversize is passed through a 20×10-in. Allis-Chalmers Blake crusher, which reduces all the rock to 2½ in. The crushed ore joins the undersize from the trommel on the conveyor belt.

The incline conveyor delivers the ore to a cross conveyor which reaches over the top of the mill bin and, by means of a Robbins tripper, the ore can be delivered at any desired point in the bin. The bin is of wooden construction with flat bottom and has a capacity of 1000 tons of rock.

Suspended Challenge feeders deliver the ore to the stamps, of which there are 40 of 1500 lb. each, dropping in a narrow mortar of the type used for speed crushing. The height of drop is 6¼ in. and the frequency is 100 drops per minute.

The screens used in the battery are of the slot form of wire cloth, the size used being about six mesh in width and about ¼ in. long.

Experiments made on crushing capacity show that through a 14-mesh screen of this type a capacity of eight tons per stamp per 24 hr. is obtained; with 6-mesh, 9½ tons and with 4-mesh, 12½ tons. The screen normally used at the present time is the 6-mesh and a regular crushing of 9½ tons, possibly a little in excess of this figure, is obtained.

Crushing is done in cyanide solution of 1½ lb. KCN per ton, the ratio being five of solution to one of ore. The mortars are arranged so that the height of discharge is two inches.

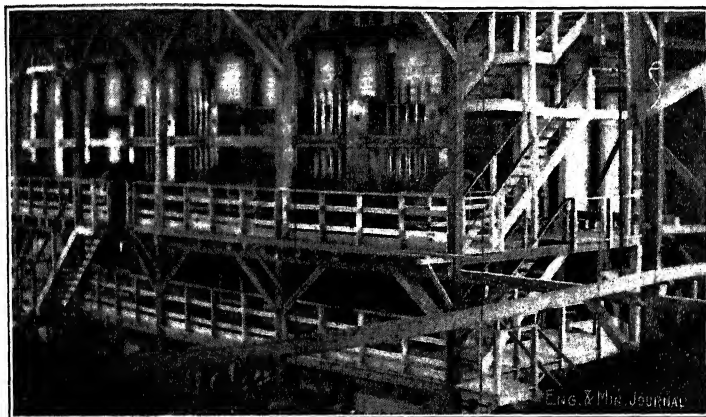
Classifier and Tube-mill Arrangement.—From the stamps the ore is carried by gravity to four Dorr duplex classifiers of the Belmont type. This type of machine is fitted with a crank arrangement with which the rakes may be lifted above the bed of sand and the machine started. This is of great service when a large amount of sand has settled in the classifier after a shutdown, the rakes being gradually lowered into the settled sand and raking it out by degrees.

The sand from the classifiers is reground in four Allis-Chalmers tube mills each 5×20 ft. They are lined with silex brick, the brick being set on edge in the mill, thus giving thickness which aids in giving long life of the lining. At present no idea of the life of these linings can be obtained because the original linings are at work and do not show any great indications of wear.

The tube mills are fitted with special spiral scoop feeders, 22 in. in diameter. Through these feeders the daily addition of pebbles is also put into the mill. The pebble charge is about six tons to each mill and the consumption is approximately two pounds per ton of ore ground. The consumption of pebbles was higher at first, reaching four pounds per ton at one time, but is gradually becoming less and it is expected that the normal consumption will remain at about two pounds per ton.

The consistency of the pulp fed to the tube mills varies somewhat from that usually considered most efficient and is the result of experiments undertaken to determine the most efficient dilution. The weight of the solids in this case makes it most efficient to use a thick pulp, 33% moisture having proved to give the best results. The mills make 28 r.p.m., use No. 1 Danish pebbles and grind 90 tons per 24 hr. to a point such that 90% passes a 200-mesh screen. The illustration shows the arrangement of the stamps, classifiers and tube mills.

Driving the Stamps and Tube Mills.—At this mill an original device, by means of which a unit of 10 stamps and one tube mill is driven from one motor, is installed. The motor, of 100 h.p., is connected with a $3\frac{1}{8}$ -in. line shaft by means of a Reynolds silent-chain drive, and this shaft passes



STAMPS AT THE HOLLINGER MILL.

to stamp-mill line shaft, of $2\frac{1}{8}$ in., at right angles, moving it by means of a miter gear. The motor shaft continues to the front of the batteries and is directly geared to the tube mill. The advantage claimed for this arrangement is that the full power of the motor may be utilized for starting the tube mill after a shutdown; the power is sufficient to overcome the inertia of the loaded mill, the stamps being hung up while this is done. The cam shaft for the 10 stamps, six inches in diameter, is in two parts and is driven by a pulley on each end. The arrangement of the driving

motor and shafts is shown in the accompanying plan of the mill. This arrangement, while having the advantage claimed for it, has also the apparent disadvantage of being subject to breakage due to the crystallization of the metal of the gears from the constant vibration caused by the stamps. As a matter of fact some of these gears have already broken, but it is considered that the advantages of the system outweigh the disadvantages.

Removing Gold by Concentration.—The slime product from the classifiers is led to a series of wooden dewatering boxes, 20 in number, each $6 \times 6 \times 6$ ft., having pointed bottom and goose-neck discharge. This dewatering plant is really two 10-compartment spitzkasten, and is used to obtain a pulp thick enough for efficient concentration. The underflow from the spitzkasten, at a dilution of three of solution to one of solids, is led to 40 No. 3 Deister slime concentrators. The concentrators are installed for the sole purpose of removing from the pulp the comparatively coarse particles of gold which would require a long time to dissolve in the cyanide solutions used. There is not a great deal of this gold that ever appears on the tables, most of it being retained in the tube mill and ground until it is dissolved in the solution.

Gold, even in fine state, does not show on the tables unless there has been an unusual quantity of extremely high-grade ore milled, which is exceptional. The expectation, when the mill was designed, was that there would be a large quantity of comparatively coarse gold, which would come out of the tube mill and would take such a long time to dissolve in cyanide solution that there would be danger of its being incompletely dissolved and discharged in the tailing. This idea has proved to be generally incorrect, the coarser particles of gold being ground up and dissolved to a great extent in the tube mill. The concentrate recovered, however, is high in gold and is treated separately on the ground.

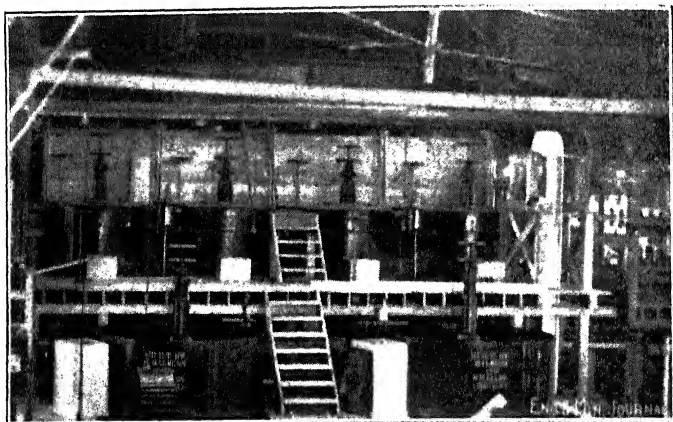
Amalgamation of Concentrate.—The concentrate from the tables drops directly into conduits in the floor, which are equipped with spiral steel conveyors by means of which it is conveyed to the end of the concentrator room, where it is received by a cross conveyor of the same type and delivered into the boot of a belt-and-bucket elevator. This spiral conveying system would seem to be a rather expensive way of conveying concentrate on account of the large amount of power usually consumed by machinery of that class. Screw conveyors are usually not considered altogether satisfactory on that account.

The concentrate is elevated to a launder which delivers it into four wooden, flat-bottom bins, each $4 \times 7 \times 5$ ft., where it is stored and shoveled out as required in the amalgamation treatment.

There are installed four Chalmers & Williams standard Wheeler pans, five feet in diameter, and into each of these is charged 1.5 tons of concentrate, 100 lb. of mercury and some lye for keeping the mercury clean, the

pan being filled up with solution. The mullers of the pan are let down and grinding is continued for one hour, after which three hours are devoted to amalgamation. The pulp is then passed to two 8-ft. settlers, where settling is completed in four hours, the amalgam being drawn off and cleaned up in a small clean-up pan. In this way about 97½% of the gold contained in the concentrate is recovered, the amalgam being sent to the refinery, where it is retorted and the resultant sponge added to the bullion obtained from the regular cyanide treatment.

As already mentioned, the original scheme of treatment included this concentration and amalgamation for the purpose of taking care of the expected quantity of coarse gold, but that has not been encountered in practice and it is altogether probable, according to the management, that



REGRINDING AND AMALGAMATING PANS AT THE HOLLINGER MILL.

this step in the process can be left out, the straight cyanide treatment being able to recover as much gold without it. Experiments toward this end are being undertaken and a decision will be made within a few months as to the course which will be pursued. The illustration shows the present installation of bins, pans and settlers, together with the elevator which brings the concentrate from the level of the concentrator room.

Mechanical Pulp Thickening. The tailing from the concentrators is joined by the solution which was taken from it by the spitzkasten and goes to two Aldrich triplex slime pumps, each 10×12 in., which deliver to four Dorr thickeners. These thickener tanks are 30×12 ft. and the scraper arms make $\frac{1}{6}$ revolution per minute.

Each triplex pump is operated by a 10-hp. motor and lifts the slime in an 8-in. spiral-riveted pipe through 30 ft. to deliver into the thickeners. The pulp from the amalgamation treatment joins the concentrator tailing

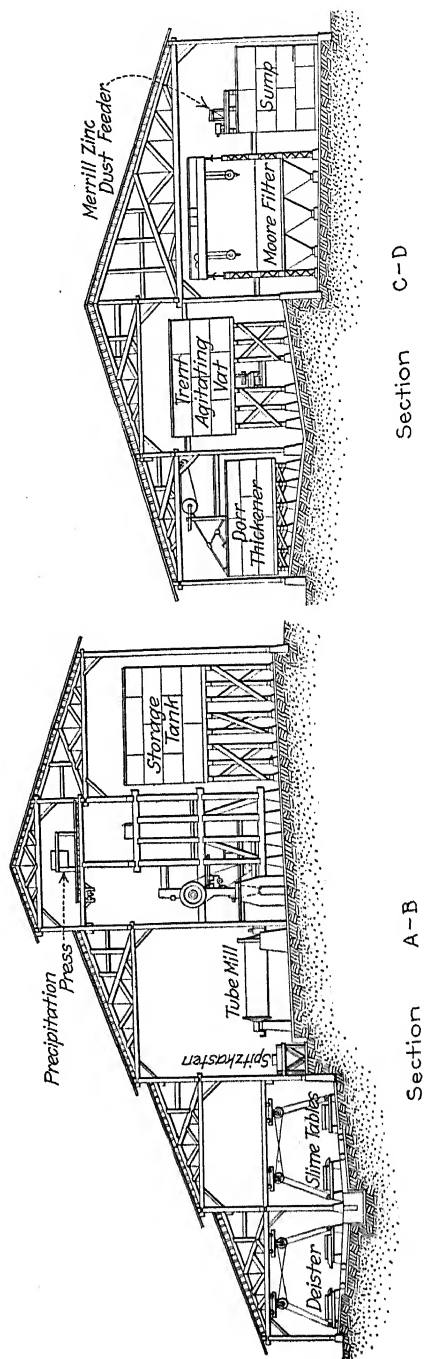
thickeners deliver an underflow containing 48% moisture which is elevated in two belt-and-bucket elevators with 10-in. buckets into the treatment tanks.

The pulp going into the Dorr thickeners receives the lime which is required for treatment. The dry lime in a fine state is put into a small pan and an emulsion is made, which is fed continuously into the pulp as it enters the thickeners. A portion of the lime is so coarse that it does not dissolve or float out of the emulsifying pan, and this portion is recovered and put into the mortars of the battery, where it is soon ground up and dissolved. The total quantity of lime added is at the rate of five pounds per ton of dry ore.

Agitation of Heavy Solids.—There are four agitating tanks each 30×15 ft. with flat bottoms which are equipped with Trent agitators operated by 6-in. Morris centrifugal pumps. The pulp is treated continuously through three of these tanks, the length of time of this passage being about 48 hr., experience having shown that this is sufficient time for treatment; the fourth tank is reserved as a spare. Due to the high specific gravity of the solids these agitators have been unsuccessful in handling the pulp in the agitation tanks. The pulp cannot be successfully agitated if this is thicker than 3:1, the power for moving the arms running as high as 18 hp. per tank.

At the 3:1 dilution the sand and granular slime settle in the tanks, stopping the agitator arms and giving an endless amount of trouble. This trouble extends to the filtration department where, on account of having to filter a dilute pulp, the operation cannot be performed in an efficient manner. On account of the difficulty experienced with these agitators it has been decided to remove them and install an agitator of a different type, which will be described. With the Trent agitators, in addition to the difficulty inside the tank, there is the difficulty experienced with the use of centrifugal pumps. With the pumps used this consists principally in the difficulty and time required to take them apart and examine the interior.

The agitators to be installed are the Dorr type, which is simply a mechanism with four revolving arms equipped with rakes exactly as in the Dorr thickener but revolving at a higher speed. The slime is raked down to the center of the tank and is then lifted by means of an air lift situated in the center of the tank, circulation being down through the tank and up through the air lift in the center. The system has been tried in an experimental way at this mill and there is now under way the equipment of the spare agitation tank, with the agitation mechanism which will be given a thorough trial on a working scale. The arms will make 12 r.p.m. The solution used in treatment is 1.5 lb. KCN per ton, as is all the solution used in the mill.



Vacuum Filtration of Pulp.—The pulp from the treatment is sent to the filter plant by gravity. The filter plant consists of an installation of four baskets of 60 leaves each, the leaves being 6 ft. 6 in. wide and 9 ft. 6 in. long, and having sides nine feet deep for the top part, beside hopper bottoms which have 7 ft. 6 in. additional depth. There are six tanks in two units, each tank measuring 10 ft. 6 in. wide and 9 ft. 6 in. long, and having sides nine feet deep for the top part, beside hopper bottoms which have 7 ft. 6 in. additional depth. There are five 10×7-in. Buffalo vacuum pumps, one for each tank and one for the acid washing of the leaves. One crane handles the baskets, having a capacity of 35 tons total load. The crane has two engines, one of 40 hp. for the lift and one of 15 hp. for the lateral travel. No trouble has been experienced with the crane, it apparently being well designed somewhat light for the work it has to perform.

The cycle of operations is longer than should be necessary, 1½ hr. being allowed for loading, during which time a cake 1½ in. thick is formed. One hour is allowed for solution wash and five minutes for the water wash. Transferring the basket takes about two minutes and discharging the cake, which is done in the water washing tank, takes 15 min. The discharge is continuous, the tailing containing 10% moisture.

It is extremely difficult to get efficient washing under the conditions obtaining with this filter because the slime is so dilute and the cake so heavy that they will not stay in suspension, the result being that there is a segregation in the cake, the lighter and more impenetrable material being at the top of the leaf, while further down it is more and more granular product until the bottom of the leaf contains a porous, material which is to all intents sand, and through which the water will pass, leaving the upper part of the leaf, which contains the slime, practically unwashed. The filter tanks are supplied with water to assist in keeping the solids suspended, but they are not altogether effective and are rather troublesome to take care of.

The major part of this filter difficulty is traceable to the design of the Trent agitators. With a properly thickened slime, as has been proven in this case, less trouble will be experienced in keeping the solids in suspension and the homogeneous cake thus formed can be washed to a 97½% efficiency. It is expected that with the installation of a new system of agitation a thick pulp, 1:1, will be maintained through the agitation and filtration system with beneficial results to both.

The loading solution from the filter plant, together with the overflow solution from the Dorr thickeners, is passed through two 22×20 ft. Merrill clarifying filters and to the pregnant-solution sump. There are two, each 22×20 ft. This solution is pumped out by a 7×9-in. Aldrich triplex solution pump, into which zinc dust is added through a Merrill feeder at the rate of 0.2 lb. per ton of solution.

20-leaf 52-in. Merrill triangular precipitate presses, where the precipitate is recovered. The regular addition of cyanide is made to the gold solution before precipitation, the cyanide being ground up and dissolved in the flow of solution. No cyanide is added in any other way in this mill. The solution precipitated is about four tons to every ton of ore treated, the consumption of zinc being 0.8 lb. per ton of ore milled. The precipitated solution is sampled for tonnage and assay purposes by a tilting-bucket device.

The resulting precipitate from the cyanide treatment is fluxed in the following proportions: Precipitate, 100; borax, 20; soda, 7; and silic, 3. It is melted in a Monarch tilting furnace using oil fuel, in a No. 275 graphite crucible, the bullion being remelted in a No. 60 crucible. The resulting bullion is about 760 fine in gold. It is contemplated that later a lead stack will be installed for the purpose of melting down the precipitate with litharge and then cupelling it in an appropriate test. By this means a finer bullion will be produced.

A plant for sampling the ore going to the mill will be erected at some time in the near future. At present every car of ore is weighed and a sample of it taken so that some idea of the work done may be obtained. The new plant will contain Snyder and Vezin samplers and a proportion of the entire ore will be cut out, reduced in small rolls and crushers and the ensuing sample reserved for assay.

The total power required to operate the mill is about 500 h.p., electrical current being used for all purposes. The mill is of wood construction, well built, and is covered with corrugated iron. It is sheathed inside with wood over a layer of tarred paper and is amply heated with steam, making a comfortable mill to work in during the winter season.

Metallurgical Simplicity. There are no great metallurgical difficulties, those that were expected before operations were commenced having failed to materialize. The ore is clean and contains no rebellious elements and the gold dissolves easily in the weak cyanide solutions used. The ore does not develop much acid as is shown by the small quantity of lime used during the treatment. It might be safely said that the only problems which have been encountered are the mechanical ones already mentioned as due to the high specific gravity and granular character of the solids in the pulp.

The recovery of gold is thoroughly satisfactory, a total extraction of 93% being obtained even under the present circumstances of mechanical imperfection. Of the gold recovered, about 85% is dissolved in the grinding operations, which are intended to include stamping, classifying and tube milling, and 15% in the agitation department. The high percentage of gold dissolved in grinding is worthy of note. It is usually true that a large proportion of metals is dissolved in the grinding department,

but not much attention has been given to a study of the fact and utilization of the opportunity presented.

The dissolving rate is largely due to the efficiency of the tube mill as an agitating machine, the grinding action of pebbles liberating and cleaning the gold and getting it in contact with solution in a condition most conducive to prompt dissolution. For this reason it is good practice to make the most of the tube-mill action and do everything to assist the extraction of metal at this point. I believe it is a good thing to freshen up the solution just before going into the tube mill either by adding fresh cyanide, part or all of the addition that is regularly made, or by using a solution which has been freshly rejuvenated by means of some one of the accepted methods.

The general run of ore milled has a value of about \$20 per ton, of which about 98% is recovered in the mill. The mill started operations in June of this year and the greater part of the elapsed time has been taken up in systematizing the operation, making necessary minor changes and in general tuning up the mill so that a normal basis of cost could be obtained. The mill is now running well and the cost is not excessive, but the management desire to establish the costs firmly before publishing any data.

The mill is well built, compact and convenient, and reflects credit on its constructing engineer, A. G. Kirby. The operations of the Hollinger Gold Mines, Ltd., are under the direction of P. A. Robbins, manager, and the mill is superintended by Noel Cunningham.

CHAPTER V

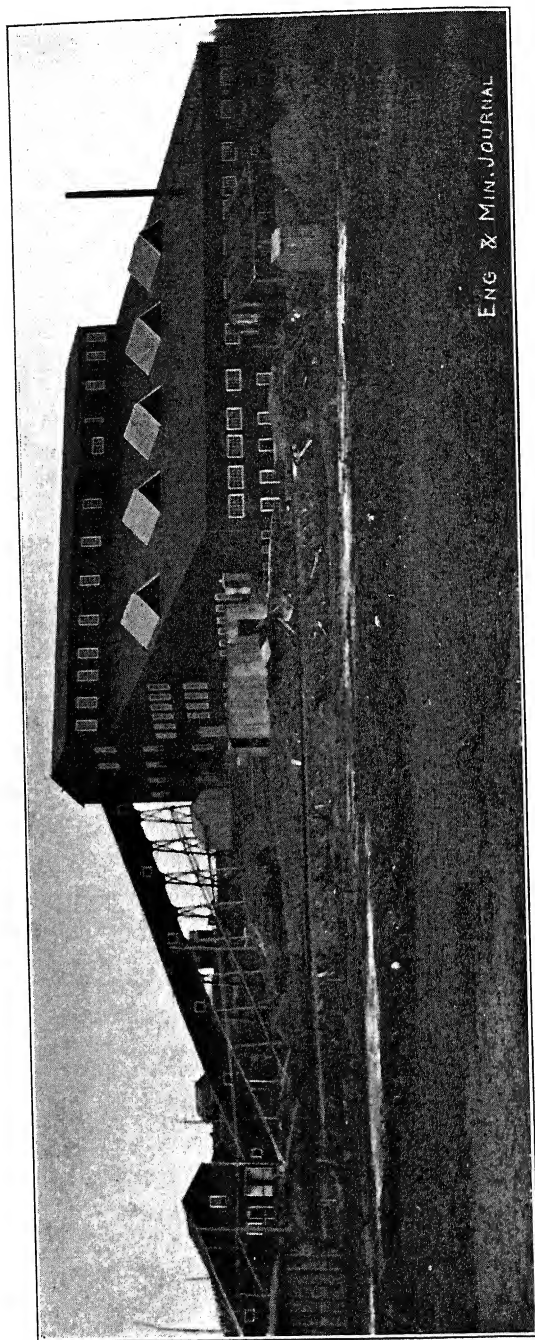
CYANIDING AT THE DOME MILL

The property of the Dome Mines Co., Ltd., is situated about 2½ miles west of the town of South Porcupine, Ont. The property is famous as the first discovery in the district, and has been the subject of great interest and discussion among mining men. It has been developed for some time, and is now equipped with a modern mining plant, a power plant, a modern 40-stamp mill and cyanide plant, started in March, 1912.

Typical Porcupine Ore.—The ore is white quartz and schist, the quartz occurring as stringers and veins of various width running in different directions through the schist country. Within the payable zone the rock is so impregnated with gold that no attempt is made to separate it, the whole product being sent to the mill as mined. The ore is similar in character to that of the Hollinger mine, but the Dome ore is harder, though it does not reach a point where it could be called difficult to crush. In common with the ores of the camp and district in general, it has a high specific gravity, the dry slime treated in the mill having a specific gravity of about 2.8, and the resultant slime is largely granular in character. It has been determined that the pulp under treatment contains about 35% colloid slime, the rest of the product being granular and heavy.

The mill is a modern structure with steel frame, concrete foundations and floors, and, a feature which is often forgotten in mill construction, excellently lighted with windows and skylights, making it easy and convenient to work in any part of the mill without artificial light in the day time. In view of the prevailing gloomy weather of the district, this is a distinct advantage tending toward more and better work and has a real value in dollars and cents. The building is heated by steam, a separate boiler installed in the mill for that purpose being of sufficient size to make the building comfortable at all times.

The ore going to the mill comes from two different places, two sets of tracks entering the crusher house. The crusher house is separate from the mill and is on the ground level. The ore, entering in cars moved by a hoist with an endless wire rope, is thrown first into a No. 7½ Kennedy gyratory crusher. This crusher discharges to a grizzly with 1½-in. openings. The oversize is put through two No. 3 Kennedy gyratory crushers. All the ore, after passing through these crushers, will pass a 1½-in. ring. This is somewhat smaller than is usually necessary for feeding stamps, but in the case of the Dome ore experience has proved that if crushing is not

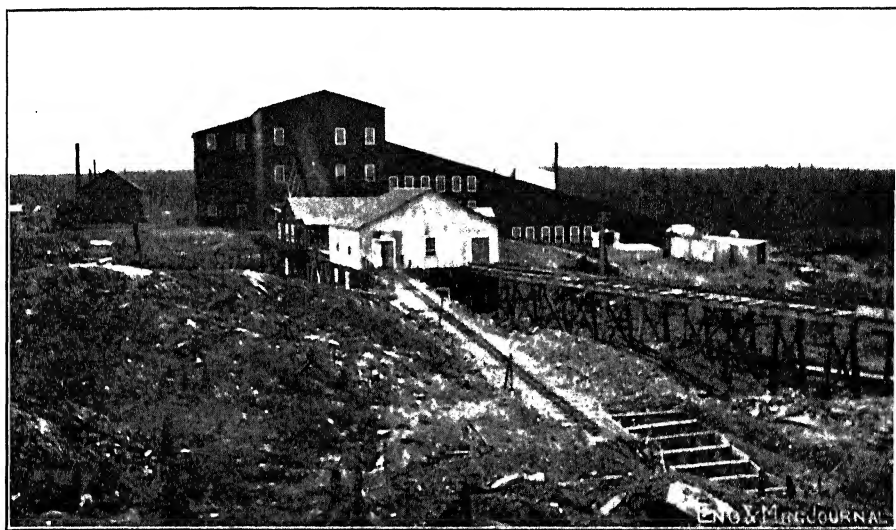


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DOME MILL, PORCUPINE DISTRICT, ONT.

rather fine, slab-shaped pieces of ore are likely to pass through the crushers without being sufficiently reduced. To avoid this condition, the crushers are set rather close, and the result is that the product is all of a good size to go through the feeders and into the mortars.

Ore Delivery from Mine to Mill.—The ore from the final crushers falls upon an inclined belt conveyor by means of which it is carried into the mill bins. The belt is 20 in. wide and rises at an incline of about $20\frac{1}{2}^{\circ}$, the belt traveling at the rate of 350 ft. per min. At the point where the conveyor enters the mill the conveyor way is closed with an iron door and a heavy iron wall is interposed between it and the mill building, only a small opening being left through which the belt passes. This



DOME MILL CRUSHER HOUSE AND INCLINE IN FOREGROUND.

arrangement is for protection against fire, the crusher house and the conveyor way not being constructed in a way to resist fire as the rest of the mill is. The half-tone engraving shows the conveyor reaching from the crusher house to the mill.

The inclined conveyor delivers the ore to a second conveyor which reaches across the bins. The second conveyor is provided with a tripper so that the ore can be delivered into any desired part of the bins. This belt is also 20 in. wide.

The mill bin is of steel construction and has a flat bottom. It has a capacity of about 1500 tons of ore and is placed back of the stamps. The ore going to the bins is not weighed, but carloads are weighed at intervals and an estimation of the quantity is made. A rough sample of the coarse

ore is taken, also one of the pulp issuing from the battery at the lip of the mortar, but no absolute system has been devised to record the content of the ore milled. According to the general results obtained it may be said that the ordinary milling ore averages about $\frac{1}{2}$ oz. in gold.

Crushing in Water.—From the bins the ore is fed into 40 1250-lb. stamps by means of suspended Challenge feeders. The stamps drop through $6\frac{1}{2}$ in. 100 times per minute and crush through a rolled slot wire screen equal to 10 mesh. On this ore and with the screen mentioned the stamps have a capacity of 10 tons per stamp per day, but owing to the limitations of the cyanide plant the actual crushing is a little under that figure, the 40 stamps crushing generally about 380 tons per day. Water is used in crushing at the rate of about $6\frac{1}{2}$:1 of ore.

Just outside the batteries are the primary amalgamating plates, one for each ten stamps, 54×144 in., in two sections, the grade being $1\frac{1}{2}$ in. per ft. These plates are intended to recover coarse gold coming from the batteries, in which there is no provision for amalgamation, but due to the scouring effect of the heavy rush of coarse pulp they are of little use. One of these plates has already been experimentally discontinued and it is likely that the others will be put out of commission.

From the primary plates the pulp is passed through four Dorr duplex classifiers where the sand is taken out and sent to four Allis-Chalmers tube mills, each 5×22 ft., having spiral scoop feeders and reverse-spiral discharge, which tends to prevent pebbles issuing from the mill and also is convenient for the introduction of the regular daily addition of pebbles which can thus be fed into the discharge end of the mill without trouble. From the tube mills the pulp is returned to the Dorr classifiers by means of five Frenier pumps, each 8×54 in., the tube mills and classifiers thus being in a closed circuit. The tube mills make 32 r.p.m. which is somewhat excessive, the general speed of mills of this size being about 28 r.p.m. Due to the weight of the pulp it may be fed into the tube mills somewhat thicker than in usual practice.

From the classifier the fine pulp, or slime, goes over a second series of plates, called the secondary plates, where amalgamation takes place. These plates are 108×144 in. with a slope of $\frac{1}{2}$ in. per foot. On these plates under present conditions of operation about 60 to 65% of the gold content of the ore is recovered.

The whole of this crushing and grinding operation is carried out in water, the reason being that a flow of cyanide solution is believed to be prejudicial to good work on the amalgamating plates.

From the secondary plates the pulp is led to three Dorr thickeners, each 30×10 ft., where the pulp is thickened as much as possible, the usual effluent being about 1:1. From the thickeners it goes to the boot of a duplex belt-and-bucket elevator, 70 ft. between centers and

carrying 7×16-in. buckets. This elevator delivers to the agitation system.

In the boot of the elevator the cyanide necessary for treatment is added, the material in lump form being suspended in the flow of pulp where it dissolves. The solution is made to a strength of one pound per ton of solution, the average consumption in total being about 0.8 lb. per ton of ore treated. The dilution ratio varies between 1:1 and 1½:1.

The classification of the pulp going to agitation is about as follows: +100 mesh, 8%; +200 mesh, 32%; -200 mesh, 60%. The fineness of grinding is controlled entirely by the comparison of cost and recovery, and the most efficient condition for both considerations has been found to be the condition above stated.

The water from the pulp is returned to the battery circuit for further use, the circulation being maintained separate. It is of course necessary to take out as much water as possible from the pulp which is to go to cyanidation treatment, in order that the consumption of cyanide shall be as low as possible.

Pachuca-tank Agitation. For agitation of the pulp Pachuca tanks are used, but the design varies from the usual standard. These tanks are 8 ft. in diameter and 40 ft. deep, resembling a chimney more than a tank. This form was adopted in view of the especially heavy character of the slime to be treated, it being considered that in a wider tank there would be danger of settling of the solids. It is stated that 35 to 40 lb. of air pressure is sufficient to secure satisfactory agitation in these tall tanks. They seem a peculiar form of agitator, but if they are, as is claimed, the most satisfactory form for agitating this heavy pulp, no criticism can be made of them.

The agitation is continuous through the Pachuca tanks, of which there are four, the last tank being arranged so that its overflow may take out a quantity equal to that which enters the tank, or may be changed so as to take out more or less, according to the desirability of increasing or reducing the amount of material in the tank. The dilution of the pulp during this treatment is from 1:1 to 1½:1 and varies somewhat in accordance with the work of the thickeners. The height of these tanks results in an advantage in that a considerable fall is secured to the filters, allowing them to be filled by gravity.

The pulp from the agitation system goes into two Dorr thickeners, each 25×10 ft., where the pulp is thickened for filtration and then into a mechanical agitator tank where the slime for filtering is stored, the slow agitation preventing the solids from settling in the tank. The overflow from these two thickeners is passed through a Merrill clarifying press and is precipitated.

Glass bottoms are used in many of the launders at the Dome mill in

order to facilitate the flow of pulp. It has been shown that with the same grade a launder having a glass bottom runs cleaner and easier and at the same time lasts longer than one without it. The glass seems to reduce friction, so that often a launder which gives trouble when made of wood or iron will flow easily and without trouble when glass bottoms are put in. A sudden drop or fall of the pulp on glass must be avoided, for in such cases the glass grinds out sooner than when iron is used. The cost is low, scrap plate glass being used, which may be bought for about seven cents per foot for pieces of various length 12 in. wide.

Pressure Filtration.—The pulp is led from the mechanical agitator to two Merrill slime presses, standard type, having 76 frames 4 inches thick. The press is filled by gravity and the slime being thick, there is no segregation and a homogeneous cake is made. Once made, the cake is washed with barren solution, an amount equal to the weight of the cake being used. During this wash there is an appreciable additional solution of gold. After the solution wash the cake is discharged, there being no actual water wash in the press, but as it requires four or five parts of water under 80 lb. pressure to discharge the slime, there results a form of washing, as most of the water is afterward recovered in the two Dorr thickeners, each 30×10 ft., through which the sluicing mixture is passed.

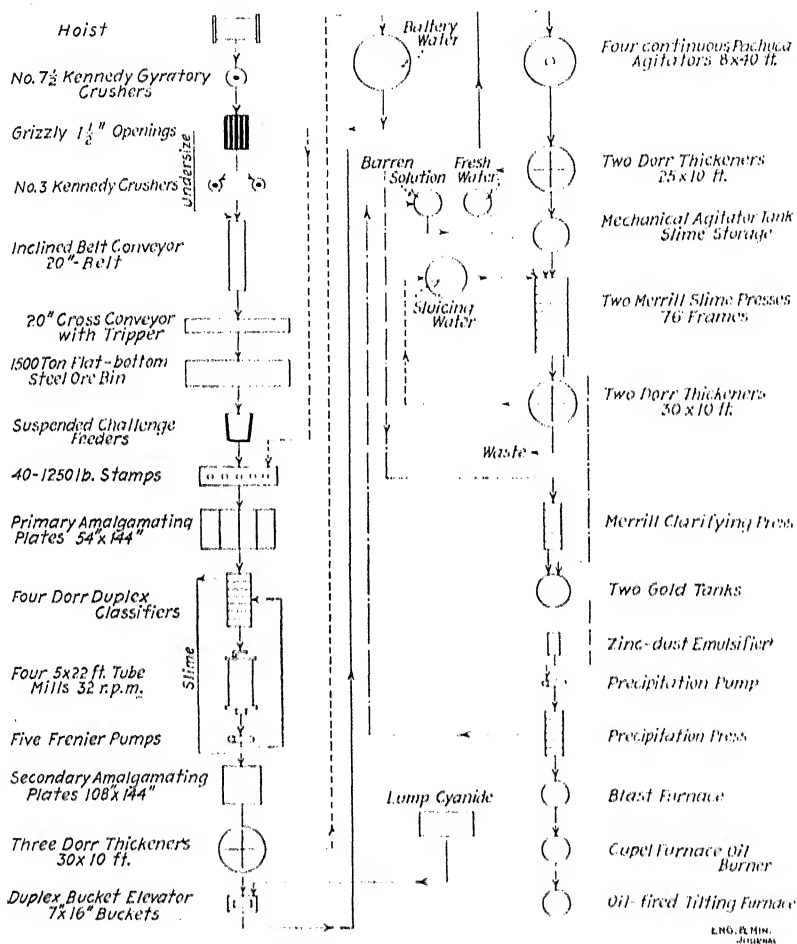
Only an equal amount of water is discharged with the slime, the rest being recovered from the thickeners and used again to sluice out the presses. The amount of wash water discharged is about equal to the quantity of water taken into treatment from the crushing system. The slime is discharged from the thickeners by gravity. This system is well adapted to the character of the pulp, the heavy solids having no time to settle previous to filling the press, with the result that a cake which can be thoroughly washed with solution is formed.

Zinc-dust Precipitation.—The Merrill system of zinc-dust precipitation is used, the zinc being added to the solution from the clarifying press which passes to the two pregnant-solution sumps, from where it is pumped into the precipitation press, which has ten 2-in. frames. The zinc is added by a spiral-screw conveyor which feeds the dust into a miniature tube mill where an emulsion of solution and zinc is formed, this emulsion going into the stream of solution entering the pump.

The amount of zinc added is approximately $\frac{1}{8}$ lb. for every ton of solution. As there are about two tons of solution precipitated for every ton of ore treated, the consumption of zinc is about $\frac{1}{4}$ lb., or approximately two cents per ton of ore milled.

A small amount of lime is used in the treatment, the system being the formation of milk of lime by placing the dry pulverized lime in a barrel and adding a constant stream of solution, the outgoing solution, or milk of lime, entering the treatment at the desired points. About three-

fourths of the total lime consumption is added to the thickeners which prepare the pulp for the agitation treatment, this being to assist settlement and aid in the production of a thick pulp; the remaining one-fourth is added to the thick pulp going to treatment. The total consumption of lime is a little under three pounds per ton of ore treated, as the ore is not extremely acid, and the lime is used more to assist settlement than for any other purpose.



FLOW SHEET OF DOME MILL.

A total of approximately 95% of the gold content of the ore is recovered, about 65% of which is recovered on the plates as has been mentioned, and the remaining quantity in the cyanide treatment. The percentage recovery is governed by the economic question, there being no difficulty in recovering 98 or 99% of the gold if it is desired to do so.

Experience has shown that it is more advisable to stop at the point now established than to attempt to extract more of it. The costs established are proportionately less than if the higher extractions were obtained.

The power used by the company is generated in its own power house by steam, using coal as fuel, and is higher than would be the case were hydro-electric power available. It is expected that such power will be delivered at the plant within the next few months, when a corresponding reduction of cost is expected. Detailed treatment costs are not given at this time as such figures to be of any service should be representative of permanent conditions.

Smelting the Precipitate.—The precipitate is melted in a small blast furnace with litharge, the resulting lead bullion being afterward cupelled in an appropriate test. The cost of this system of refining seems to be less than the older method of direct melting and a practically fine bullion is obtained, with the advantages which come with a product of that kind. The lead stack is easy to operate and does not entail the severe labor attendant upon pot melting, and the cupelling operation is also comparatively clean and convenient. A comparison of the cost will add the deciding factor, and I expect to give especial attention to this matter in future papers on the subject.

At the Dome mill the cupelled bullion is melted and made into bars in a small oil-fired tilting furnace. For this purpose the tilting furnace is satisfactory.

The cupel furnace is heated by means of an oil burner, but the operators consider that it is not as satisfactory as when wood fuel is used. The cupel itself is made of a mixture of ground limestone and Portland cement in the proportions of about 1 : 3, which makes a properly absorbent test. The saturated portions are melted down in the blast furnace together with scraps, sweepings, etc., in a scavenger run which is made at intervals.

Points for Discussion.—The first point in the Dome mill which is open to criticism of any kind is the fact that no accurate weighing or sampling is done on the ore which enters the mill. Estimations are made, but these can hardly be considered an effective substitute for absolute methods and probably much more satisfaction would be obtained with accurate weighing and sampling systems such as are being installed in the newer mills. The pulp from the Dorr thickeners going to the agitation treatment is estimated by measurement and specific gravity determinations which are taken at regular intervals and the operators believe that in this way a good estimate of the tonnage is obtained.

Pachuca tanks as here used seem to be a subject for some discussion, but personally I think there might be some more satisfactory and

economical method of obtaining the same result. I am not convinced that Pachuca tanks are most efficient agitators, particularly where the time of contact is short and where great agitation is not necessary. The fall for the filters could as well be secured by using tanks of different form, even if the elevation were made equal to that now obtained.

A comparison of the design of the Hollinger and Dome mills presents a good illustration of two ways of doing the same thing. In both mills the original design contemplated the removal of coarse gold which might not be dissolved in the cyanide solutions and which, it was feared, might be discharged undissolved with the residues. At the Hollinger the attempt was made to extract this coarse gold on concentrators, while at the Dome mill the same result is sought through the medium of amalgamating plates. It is probable that neither system is necessary.

At the Hollinger mill it has been demonstrated that this coarse gold is more than likely to be retained in the tube mill as long as it is coarse, and being there scoured and subjected to attrition it is generally reduced and dissolved. The concentration system is already under suspicion of being useless and may be dispensed with. At the Dome the system of amalgamation on plates is done in water which has to be carried through the whole grinding system and this presents the serious defect of losing the dissolving effect of the solution during crushing and grinding, and particularly the highly efficient dissolving action of the tube-milling operation.

I am of the opinion that the simplification of the mill through the discarding of the plates and grinding directly in cyanide solutions would obtain a result as good or better than the one now in use and perhaps at less cost. A great advantage about the latter system is that not so much water would be necessarily taken into the circulation. None would be taken in through milling and what water is required could be taken into circulation through giving the filter cake a water wash. This would reduce the loss in dissolved gold and also the mechanical loss of cyanide, which constitutes at present about two-thirds of the total loss.

The logical addition of water to milling systems is through the filter cake where it will do the most good, and not into the agitation circuit where it merely dilutes solutions and necessitates the addition of cyanide to keep strengths up to normal.

It is still an open question whether or not economies could be introduced by using a system of partial leaching, agitating only the natural slime formed during grinding and passing the fine, granular solids to a leaching system. This question can only be solved by a series of experiments establishing the point to which grinding must be carried to liberate the maximum quantity of gold and the desirability of either leaching or agitating the fine sand, according to cost.

The filtration system at the Dome mill, using the Merrill pressure filter, is the best I have seen in Canada. The character of the pulp makes the machine especially applicable to handling it, and filtration is performed at a minimum expense and with beautiful simplicity. The pressure system ought to be installed in all mills to be built even if it does not displace vacuum plants already installed. With the change from the Dome practice of adding a water wash to the cake, it seems to me that most admirable results might be obtained.

At the Dome mill the metallurgical difficulties are negligible. The problems are all mechanical, due to the handling of the heavy pulp and the devising of a system of manipulation which will give the highest economy.

DISCUSSION

Cyaniding at the Dome Mill

I read with interest the article by Mr. McGraw in the *JOURNAL* of Nov. 23, 1912, describing the milling practice of the Dome Mines Co., at Porcupine, Ont. I notice that the writer seems to consider the ratio between the width and height (8:40) of the Pachuca agitators unusual, but in an all-sliming process such as followed at the above-mentioned property it is doubtful if efficient agitation could be obtained with a more shallow, wider tank. F. C. Brown, in giving specifications for Pachuca tanks (*Min. and Sci. Press*, Sept. 26, 1908), placed the ratio between the width and height of standard tanks at $1:4\frac{1}{2}$ or 5, hence that observed at the Dome plant does not appear to be excessive.

In Pachuca construction there seems to be a general tendency to build a lower, wider tank, either from motives of economy in construction, or from the fact that in many cases the tanks are simply remodeled agitators of some other type. While a tank of this kind will give fair results when working on a pure slime, in all-sliming practice where a large percentage of material consists of fine angular grains of sand, trouble is bound to be experienced in the close packing of these particles. In fact, I believe that the greater part of the difficulty encountered in this system of agitation is due to the reason that the proper ratio of width to height has been neglected in the construction of the tanks.

With respect to the Dome plant, and taking into consideration the all-sliming method in use there, I do not see how any other system would handle successfully such a heavy pulp, containing, as it certainly must, a large percentage of angular, fast-settling particles. Mechanical agitation under the above conditions would entail an extremely high repair cost, resulting from the strain on the machinery. The only alternative to the

present treatment, it seems to me, would be to divide the mill product into sand and slime, and treat each separately. Considering the matter from this viewpoint, and from the fact that the time spent in leaching would be offset by a lower power cost, I do not see why the older method would not be successful.

As regards amalgamation, I am quite in accord with Mr. McGraw; it appears to me unnecessary.

J. A. REID.

Kingston, Ont., Dec. 1, 1912.

CHAPTER VI

PRACTICE IN THE BLACK HILLS, SOUTH DAKOTA

The mineral district of the Black Hills, in South Dakota, has long occupied a prominent position in the mining world, due to the extent of its deposits and their original richness. In the early days ores of high grade were obtained and as these gradually disappeared, ores of lower grade had to be depended upon to keep up production. The ingenuity of the metallurgical world was taxed to the utmost in devising methods by means of which profits might be obtained from rebellious ores containing only small quantities of gold and silver. The whole gamut of metallurgical methods has been played upon in the effort to treat the ores economically.

Victory of Cyanidation.—Such processes as smelting, pan amalgamation, bromination, chlorination, plate amalgamation, all had their day and were thoroughly tried, but nothing made any noteworthy success until cyanidation was tried, proved available, and applied on a large scale to the treatment of the ores. Cyanidation has been the means by which enormous quantities of low-grade ores have been made economically available and millions of dollars have been taken from ores which by no other means could be beneficiated at a profit. It is probable that in no other mining district has cyanidation had a greater beneficial effect.

The first application of cyanide in the Black Hills was at the Rossiter plant in 1892, but great and decided success was not demonstrated until 1900, since which time the applications of the process have increased, until at present there is no successful installation which does not make use of the process in some form.

The ores are in the main siliceous, containing silica in the form of quartz and in proportions varying between 75 and 90 %. The unaltered blue ores contain less than the red oxidized mineral. The blue ores contain also an average of from 6 to 8% of pyrites, fine and evenly distributed, though some of them contain as high as 20%. In the red ores the pyrite has been oxidized to form the iron oxides which give the ore its color. Tellurium has been found in some minerals and the existence of tellurides of gold and silver is maintained by some authorities. Copper occurs in minute proportions in many of the minerals. At some of the larger mills, notably the Homestake, copper is always present

in the precipitate, but this is believed to be due principally to the caps used in detonating the charges of explosives and from other similar sources, although copper does exist in the ore. The gold is in an extremely fine state and is rarely found free. The ores are fairly hard, in some instances extremely so, but there is also much clayey material which produces a large amount of colloid slime. All grades of hardness are found between the extremes of clay and extremely hard and close-grained rock. In most cases the mineral is heavy, the specific gravity of the solids in mill pulp often running as high as 3, while there are many graduations under that figure, all, however, being comparatively heavy.

Dry Crushing at Wasp No. 2.—One of the most interesting installations in the Black Hills is that of the Wasp No. 2 Mining Co., where a flat quartzite deposit carrying extremely small quantities of gold is being milled at a substantial profit. The ore, after passing the usual crusher system, is broken through four sets of rolls, two of which are used for roughing and two for finishing. This crushing is all performed on the dry ore. After passing the finishing roll the material will all pass a screen having $\frac{1}{4}$ -in. openings. A large proportion of the material is, of course, much finer, varying between fine sand, there being little slime, and the maximum size of $\frac{1}{4}$ -in. The crushing is carried no farther, the ore being treated in this condition. This finished product is stored in bins and is drawn out as required to charge the treatment tanks. The tanks are charged from these bins by means of a system of belt conveyors which receive the material at the bins and deliver it at about the center of the treatment tanks, where it is distributed by hand. The leaching tanks are six in number, each 32×12 ft., and hold a little over 400 tons of ore.

Treatment by Leaching.—The cyanide treatment of this ore is entirely by leaching. The practice is to add first a bath of solution carrying five pounds KCN per ton in sufficient quantity to impregnate the charge thoroughly and leave a solution covering of about an inch over it. This bath remains in contact with the charge for 12 hours, when it is drained off. The mixture of fine and coarse material offers little resistance to the passage of solutions and the leaching rate is exceptionally high, which facilitates the treatment to no small degree. It will be seen that this condition of porosity of the charge also facilitates treatment, for the reason that air for aëration of the charge readily penetrates the entire charge, following the solution through the mass.

After the strong solution has been drained off, a weaker solution is added, the strength being $2\frac{1}{2}$ lb. KCN per ton, and this treatment is continued for 48 hours, there being seven separate additions of the solution during this time. A subsequent water wash is given in quantity only sufficient to displace the solution held by the ore. The gold-bearing

solutions from this treatment are passed over zinc shavings, the resulting precipitate being dried and melted in a crucible furnace using oil fuel in the usual way.

Tonnage Estimations.—No attempt is made to sample or estimate the quantity of ore handled before it enters treatment, all calculations being made on the filled tanks before the cyanide solutions are added. In the general run of mills this would be considered faulty practice, but in this case where the ore is crushed dry and loaded into treatment tanks without any preliminary treatment or separation of any kind, it is probably as accurate as any way could be and is extremely simple. The tanks can be sampled satisfactorily by means of the pipe sampler, taking a large number of tests in different portions of the tank, and a good estimate of the weight can be made from it as well as a satisfactory sample for determining the content of the charge in gold and silver.

The cost of discharging the tanks is low, approximating only about five cents per ton. The work is accomplished by seven men, four of whom are employed inside the tank shoveling out the charge through bottom doors, and three employed in tramping out the cars, which are loaded directly under the discharge gates. The men inside the tank do not have to lift the charge at all, the process being simply to scrape the material to the discharge gates. The proportion of moisture is small and the material runs readily enough and gives no trouble. Due to this facility the tanks may be emptied in about seven hours. The tanks are charged at a rate which gives the mill a daily capacity of 500 tons.

Addition of Lime.—Lime at the rate of six pounds per ton of dry ore is added at the crushers, and is carried through the crushing system with the ore, being thus thoroughly mixed with it. The treatment solutions carry about one pound dissolved CaO , which is sufficient to protect them against any small amount of acid which the ore might develop.

The method of adding lime seems to me to be somewhat wasteful in this instance, as the ore is not entirely reduced to a fine state and it is reasonable to suppose that the lime, at least in part, will be in coarse particles. The time of treatment is not sufficient to dissolve the coarser pieces of lime entirely and it is likely that an appreciable percentage of it is discharged undissolved, occasioning a slight loss. I am of the opinion that some method of adding the lime in emulsion in the quantity actually required for protection might result in a slight reduction of the cost of lime used. A hint would be to consider the method used at the Home-stake mills for adding lime to the leaching tanks. While this method might not be applicable in exactly the same form, some simple variation of it might be productive of good results.

The extraction averages about 70% of the precious metals contained

sometimes a little more and occasionally a little less, depending on the grade of the ore handled. The cost of the treatment is exceptionally low. The entire costs of the operations are: Mining, 53.48c. per ton; milling, 66.82c.; general expense, 4.35c. The principal items in the milling cost are: Labor, 21.3c. per ton; cyanide, 6.3c.; zinc, 3.3c.; lime, 1.2c.; power, 8.4c., and supplies and repairs, 12.6c. per ton milled.

Simple Treatment at Wasp Mill.—It will be seen that the metallurgy of the Wasp ore is extremely simple. The simplicity is probably due, in a great measure, to the fact that the gold is contained in cleavage planes which are fractured and opened by the coarse crushing, thus exposing a maximum quantity to the action of cyanide solutions. Besides, the rock itself is porous and the solutions can readily enter and act upon a large portion of the gold, bringing it out without entailing the expense of fine crushing.

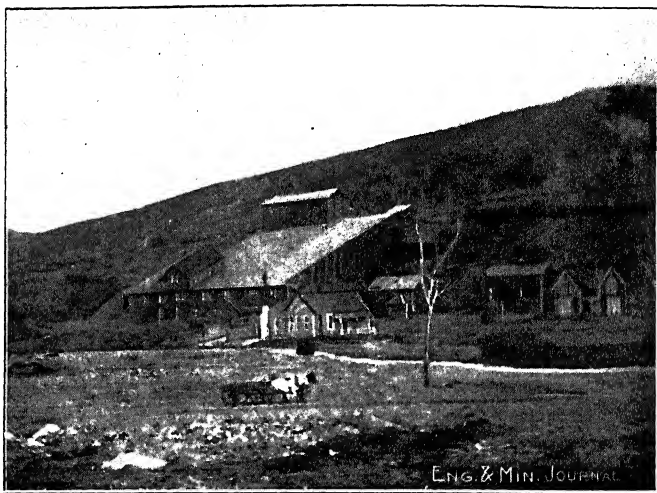
A large number of experiments have been made on this ore by competent metallurgists in order to determine whether an economical higher extraction could be obtained by grinding finer, but the conclusion has been that the maximum profit is being obtained by the system now followed. The ore carries only about \$2 per ton and will not stand a higher operation expense. It is likely that there are few examples of a similar nature in existence where a profit ranging from 50 to 75c. per ton can be obtained on ore of this low gold content. I have seen one other example, a Mexican mine which contained an ore having a good gold content. The ore was so porous that pieces $\frac{1}{2}$ in. in size would readily surrender their content to weak cyanide solutions, but this ore was in the surface zone of a vein and was soon exhausted.

Wet Crushing in Chilean Mills.—An example of conditions differing from those obtaining at the Wasp is found at the mill of the Golden Reward Mining Co. at Deadwood. This company owns mines in different districts and the ores delivered at the mill for treatment differ widely in character. Some of them are hard, while others are at the other extreme of the scale, being soft and clayey, many variations between the two being submitted for treatment. The ore is delivered to the mill in railway ore cars and is always carefully weighed before being put into the mill bins. The ore is crushed dry through a series of crushers and rolls, an automatic sample being taken during the process which is reduced in a small crushing roll, put through several quartering samplers, and finally divided in a small hand sampling machine, which delivers a sample appropriate for assaying purposes. The reject from the sampling all goes into the mill bins with the milling ore.

From the mill bins the ore is taken to Chilean mills of the modern, high-speed type, making 30 r.p.m., and is milled in cyanide solution. The feeders for these mills are similar to the challenge feeders used for

feeding stamps, but are continuously moved by power, belt and pulley, and the feed is arranged so that a practically continuous stream of ore is fed into the mills. The ore is milled to pass a 16-mesh screen.

Pulp Classification.—From the Chilean mills the pulp goes to drag classifiers of the so-called Esperanza type, which differ from the Dorr machines in that the series of scrapers is connected to a link belt, which moves continuously over sprockets, large at the slime-discharge end of the machine and smaller at the sand end. These machines are more or less efficient, but the general consensus of opinion among those who use them is that the absence of the reciprocal motion, which is obtained in the Dorr machine, allows more slime to be carried over with sand product. The reciprocal motion of the latter seems to turn over the sand, loosen it



GOLDEN REWARD MILL.

and offer facilities for washing out the greater portion of the slime mixed with it.

The separation of slime and sand is about half and half, the sand being delivered into leaching tanks, each 20×10 ft., where it is treated in the usual way by successive solution washes, followed by a final water wash. The slime is passed through Dorr thickeners and pumped into slime-storage tanks, the simple passage through the thickeners being sufficient to dissolve the economical maximum of the contained gold.

Vacuum Filtration.—From the slime-storage tanks the pulp is drawn by gravity into the Moore filter at an average dilution of about one of solid to $1\frac{1}{2}$ of solution, this rate varying with the exigencies of the occasion. The Moore plant contains two 40-leaf baskets, each leaf measur-

ing 6×8 ft. A 1-in. cake is formed on the leaf in from 40 to 60 minutes, depending on the condition of the leaves. The cake is washed with solution and water and discharged following the usual practice, the application presenting no novelties.

The proportion of colloid slime existing in the pulp makes it particularly applicable to filtration by this system and efficient results are procured with comparative ease. The problem of filtration is not a simple one in any case and it cannot be said that any of the processes in use at the present time approximate perfection to any great extent, but by applying the machine and method best adapted to any particular ore fairly satisfactory results may be obtained.

The ores treated at this mill vary widely in grade, running from a minimum of about \$5 per ton to a maximum of about \$12. An average extraction of slightly under 80% is obtained at a cost of less than \$1.50 per ton milled. The lime used in treatment, the quantity varying with the ore at hand, is added at the crushers and amounts usually to four to six pounds per ton milled. The milling capacity is about 275 tons per day.

The practice of the Golden Reward mill is typical of the modern tendency to mill in cyanide solutions, in this case the strength being about 1½ lb. KCN per ton, and although the mill is old and not particularly well adapted for securing low operation costs, the work is nevertheless efficiently done and the costs, under the circumstances, do not seem to be exorbitant.

Experimenting with Roasting Process.—The Golden Reward company possesses a large quantity of ore which has resisted the efforts of metallurgists to treat it by any of the straight milling processes and an effort is now being made to render it amenable to cyanidation by giving it a preliminary roast. Experiments have shown that after being roasted the ore is amenable to cyanidation and high extractions can be obtained without excessive consumption of cyanide or other chemicals. The cost of roasting will not be excessive as it is proposed to utilize the sulphur content as fuel as far as possible, thus reducing the consumption of extraneous fuel.

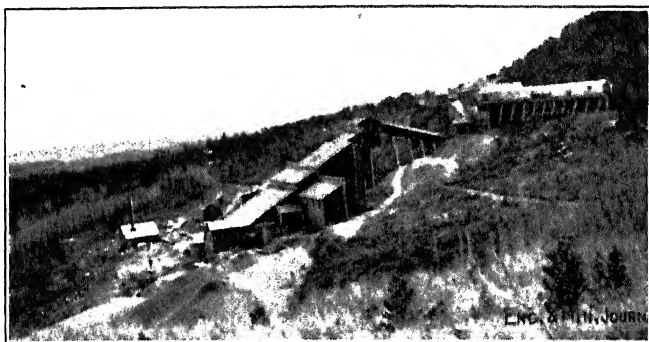
A roasting furnace is now in course of erection and will be in operation in the near future. The results obtained by this departure in metallurgical practice will be awaited with interest.

Wet Crushing through Rolls.—Another mill employing a wet crushing process and using cyanide solutions throughout is that of the Trojan Mining Co. at Portland, probably one of the most modern installations in the Black Hills. This mill formerly was the property of the American Eagle company, but was acquired by the Trojan company and remodeled to suit modern practice. The ore from the mines is dumped

into bins at the crusher house and from these bins is drawn over grizzlies, the undersize going to a belt conveyor, the oversize passing through gyratory crushers and then joining the undersize on the belt conveyor. This conveyor has a slope of about 16° and delivers ore into mill bins having a capacity of about 450 tons. An automatic sampling arrangement was at first installed to cut a sample from the ore stream falling into the bins, but the arrangement did not give a representative sample and was dismantled.

The ore is drawn from the mill bins and fed by disk feeders into two sets of crushing rolls, strong cyanide solution being added at this point. These rolls were probably not intended for wet crushing, for the housing leaks a good deal and the almost constant attention of an attendant is necessary to keep the leaks stopped up.

The product of the rolls flows through a launder to two Monadnock chilean mills, each seven feet in diameter. These mills gave some trouble



TROJAN MILL.

due to slight mechanical imperfections, but these have been remedied so that the mills now give good results. The product of the mills is elevated to Dorr classifiers where the sand and slime are separated. The sand is delivered to 200-ton leaching tanks, 28×8 ft., through automatic revolving arm distributors. The sand treatment presents no novelties, being the same as that usually followed in the district.

Air Agitation of Slime.—The slime from the classifiers is taken to three tanks for air agitation, these tanks being said to be of the Pachuca type. They measure 17 ft. 6 in. in diameter and 16 ft. in height, and it will be readily seen that they differ a great deal from the Pachuca idea in their proportions. A true Pachuca tank should have about 40 ft. of height for a diameter of 15 ft. and the Trojan tanks have a greater diameter with much less height. They are, however, doing excellent work. The dilution of the slime under treatment is about 1 or $1\frac{1}{2}$: 1, the

object being to maintain a fairly thick pulp suitable for subsequent filtering.

A detail of these tanks which is of interest is the central air-agitation tube, which is not a tube at all, but a succession of cone sections set one above another through the entire height of the tank. The idea is that, whatever the height of the pulp in the tank, it can be successfully agitated because the central tube will discharge itself at almost any point.

The slime treatment is continuous through two of the agitation tanks, the slime from the first one being transferred either to the second or third tank, as desired, by air lifts, and from these secondary tanks it is drawn off into the filter plant. The average agitation time of the slime is five to six hours, no solution being decanted but the entire pulp going to the filter.

The solution fed into the primary crushing rolls with the ore averages three pounds of KCN per ton and is added in the proportion of four to six tons of solution to one of ore. The sand in the leaching tanks is treated with this same solution for about three days, and this treatment is followed by treating two days with weak solution, which has been precipitated, containing about one pound of KCN per ton. A light water wash is given before discharging the sand, the treatment usually extending over about five days.

The filter is the ordinary Butters stationary, semi-gravity type which, while more or less satisfactory, entails a high cost for pumping pulp and solutions. From the filter the solution effluent from making cake is sent to the precipitation department, the weak barren-solution wash and the water wash not being precipitated.

Precipitation is accomplished in the usual way, using zinc shavings and the ordinary form of steel box. The boxes have a total capacity of 384 cu. ft. of zinc. At the cleanup the precipitate is run into an acid-treatment tank where the sulphuric-acid process, customary in the Black Hills plants, is carried out. The precipitate is collected, dried, partly roasted, fluxed and melted in crucibles in a coke furnace.

The capacity of the Trojan mill is about 175 to 180 tons per day, but steps are being taken to increase this tonnage materially. The extraction secured by the combined slime and sand treatment is in the neighborhood of 75%, somewhat more on the slime than on the sand product.

Unusual Crushing Practice.—The practice of crushing with cyanide solution through rolls is not usual, although it is practised in a few cases and in one other instance in this district, as will be noted. It has been productive of good results, probably due to the increased time of contact between the ore and cyanide solutions, and the agitation secured in the rolls and chilean mills.

The chilean mills are efficient crushing machines and are capable of

handling large quantities of ore, but being high-speed machines they naturally incur a maintenance cost which is high compared to the results obtained with slow-speed mills. In this connection it might be mentioned that the Minnesota mill, at Maitland, is equipped with slow-speed mills of the Lane type, and it is claimed that these mills have demonstrated their ability to crush an equal or greater quantity of ore with less expense both for operation and maintenance.

The Chilean mill is said to have been introduced into Black Hills practice by J. V. N. Dorr, who first installed them at the Lundberg, Dorr & Wilson mill and afterward included them in the design of the Mogul mill, where they gave good results. The Mogul mill was recently destroyed by fire and rebuilding is now under consideration, but the new plant will probably be built on a site more convenient to the mining properties owned by the company.

Dry Crushing of Hard Ores.—As an example of extremely hard ores found in the Black Hills district, the material handled by the Victoria mill in the Spearfish Cañon region may be mentioned. The ore here is extremely hard and the mill equipment has been designed with this characteristic in view. The ore is delivered into the mill bins by a tramway and from these bins is passed through a gyratory crusher which delivers a product that will pass a $1\frac{1}{4}$ -in. ring. This crusher product is passed through a set of rolls which delivers a product having a maximum size of $\frac{3}{8}$ in.; the crushed ore drops into a 100-ton bin.

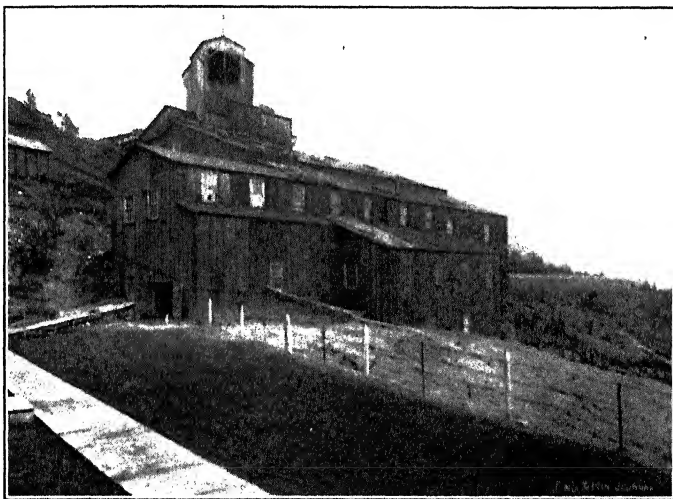
From this bin the ore passes a set of fine-crushing rolls and through a trommel, carrying 6-mesh, No. 14-wire screen. The oversize from the trommel passes to a second set of fine-crushing rolls, and through another trommel like that already mentioned. The oversize from this trommel goes back to the same rolls and the screened product from both trommels drops into a finished-product bin having a capacity of 200 tons.

The ore is so hard that its passage through the rolls is accompanied by a great deal of noise which sounds much like cannon shots, but the rolls handle the material in a satisfactory manner without undue wear.

The finished product is drawn from the bin and taken to leaching tanks by means of a belt-conveyor system. The conveyor deposits the ore into the center of the leaching tanks, each $27\frac{1}{2}$ ft. in diameter by eight feet deep, with a capacity of about 200 tons, and the distribution is by hand.

Leaching is practised in the ordinary way by first treating with a 3-lb. cyanide solution, for 72 hr. During this treatment about 70% of the gold content is dissolved. An additional 10 or 12% is obtained by leaching for a further period of 48 hr. with cyanide solution containing $1\frac{1}{2}$ lb. KCN per ton, the latter being finally displaced with a minimum water wash.

Precipitation on Zinc Shavings.—Precipitation is accomplished in the usual way, using zinc boxes of the ordinary type made of sheet steel. There are two six-compartment boxes, each compartment measuring two by three feet. Each compartment is connected by a pipe to a main which leads into the acid-treatment tank. At the cleanup the zinc is thoroughly washed and the precipitate, after settlement, is drawn through the pipes directly to the acid tank without further handling. The acid tank is lead lined and furnished with a hood by means of which the gases generated are carried off. The acid-treated product is pumped through a filter press and washed. This precipitate, after being partially dried and mixed with the usual borax-soda flux, is melted in graphite crucibles. The resulting bullion is a little more than 900 fine, of which 50 is silver.



LUNDBERG, DORR AND WILSON MILL.

The ore treated at this mill varies in value from \$4 to \$7 per ton. The mill has not been in operation for a sufficient time to standardize the costs, but it is expected that these will not average higher than those obtained at other similar mills in the district. The mill is at present treating about 200 tons per day, perhaps the average being a little under that figure.

A Mill of Historical Interest.—At Terry is situated the Lundberg, Dorr & Wilson wet-crushing cyanide mill, owned by a partnership composed of John Lundberg, J. V. N. Dorr and A. D. Wilson. For several reasons this plant is unique. It was started in January, 1904, and was the first mill in the world to operate continuously and successfully a leaf-filter plant. It was in this plant that the first filter plant designed by George Moore was installed, its difficulties encountered and over-

come; the original plant is today operating and doing good work.¹ In this plant also the well known Dorr classifier and the equally well known Dorr thickener were developed. In addition this was the first plant in the Black Hills to use the improved chilean mill for crushing in cyanide solution. The plant has operated steadily since January, 1904, except during the labor troubles of 1907 and 1910, and it has the best record for continuous operation of all the Black Hills cyanide plants. The mill has a capacity of 110 tons per day and, due to the fact that it is treating custom ores as well as ores belonging to the partnership, few details of the practice have been made public and no information as to costs has been given out.

The ore from the mines belonging to the company is held in three bins having a capacity of 135 tons and the custom ore is dumped from mining cars on the Chicago & Northwestern R.R. tracks in the rear of the mill into bins holding 80 tons, from which point it is trammed to the crushers. After passing over grizzlies with openings of $1\frac{1}{2}$ in. the ore passes through a Gates gyratory crusher and thence to a 12-in. vertical belt elevator which delivers it into a 75-ton crushed-ore bin. As the ore drops into this bin an automatic sample is cut from the stream.

Wet Crushing Rolls.—From the crushed-ore bin the material is fed by a cam feeder into a Carterville geared roll together with solution carrying $1\frac{1}{2}$ lb. KCN per ton. The solution is run in sufficient quantity to sluice the product satisfactorily through a launder into the chilean mill. This product, which will average about $\frac{3}{4}$ in. in size, passes to a 6-ft. Monadnock chilean mill, and is reduced so that practically all of it passes a 30-mesh screen. At this point sufficient clear overflow from the thickeners and cones is added to bring the quantity up to three or $3\frac{1}{2}$ tons of solution to one of ore.

The ground product from this mill is taken to a standard Dorr classifier, the sand product of which passes to one of four leaching tanks, each 18 ft. in diameter by 11 ft. deep, holding 105 tons of sand. In addition to the 32 hours required to fill each tank, the charge is given a further 12-hr. treatment with mill solution. The balance of the five-day treatment is with barren solution carrying $1\frac{1}{2}$ lb. cyanide per ton, followed by a weak-solution treatment and finally a minimum water wash. The leaching rate starts at five tons per hour and gradually diminishes toward the end of treatment at which time it is one to $1\frac{1}{2}$ tons per hour.

Slime Treatment.—Slime from the classifier, which amounts to 50 to 55% of the dry weight of the ore, is divided between two cones, one 18 ft. in diameter and the other 22 ft., and one standard 18-ft. continuous Dorr thickener. The two cones are so placed as to give a gravity flow

¹ This mill was closed down late in July, 1913, which was subsequent to the date of the present article.

of clear solution to the roll supply tank while the overflow of the thickener goes to the chilean mill. The thickened slime containing about 55% moisture is transferred by air lifts from the thickener and the 18-ft. cone to the 22-ft. cone. From the latter it goes to a small cone agitator and into the loading vat of the Moore filter, usually carrying about 55% moisture and containing from five to 10% of -200-mesh material.

First Moore Filter. This original Moore filter plant was designed in the beginning to handle 30 tons of slime per day, but it has been crowded until it now handles 60 tons daily, using two baskets. With minor changes in the construction of the plant and a change in the bottom of one tank the installation is practically the same today as when it was designed in 1903.

The crane for the transfer of the basket is operated by water at 105-lb. pressure, the water being pumped into an accumulator. It gives little trouble and costs almost nothing for maintenance. The mill solution and most of the barren-solution wash from the filter process and sand leaching go to the gold tanks and are precipitated. Solutions assaying less than \$1 per ton are not precipitated unless the treatment happens to demand additional barren-solution, or the supply of high-grade solution is insufficient to keep the precipitation department busy.

The solutions are precipitated by means of zinc shavings. In this plant barrels have always been used instead of zinc boxes, the plant having a total of 30 barrels in 10 rows of three each. They are cleaned up twice a month, the rule being to take all the contents of the head barrel, part from the second barrel and still less from the third barrel, sorting all the coarse zinc and returning it to the second barrel. The fine zinc and precipitate thus sorted out are placed directly in the acid tank. The barrels are all moved up one step, the second barrel before cleaning up becoming the first and the first barrel moved down to the foot. The second barrel, now the head of the series, is repacked, the next partially repacked; all of the fine material taken out is put in the acid tank. As the cleanup usually consists of about 100 lb. of dry product, all the figures which follow apply to a cleanup of that size.

To the product in the acid tank 415 lb. of commercial sulphuric acid are added and allowed to remain in contact for six to seven hours, or until chemical action has nearly ceased. Water in equal volume is then added and the contents are heated with live steam and allowed to stand 10 or 12 hr., usually over night. The following morning the solution is siphoned into a settling tank where any flocculent matter is settled. Another water wash is added and live steam again introduced to heat the charge thoroughly. The charge is then allowed to stand about an hour. The clear solution is drawn off into a vacuum tank and filtered. When the acid tank is nearly empty the contents are energetically stirred to

bring all of the product into suspension and the charge is transferred to a vacuum tank and filtered.

When the moisture contained is brought down to 4 or 5% the product is taken from the tank, broken so that no piece is larger than a 1-in. cube and placed in flat, iron roasting pans. These pans are placed in a soft-coal furnace and the fire is started. The furnace has a total capacity of four 18×3-in. pans in two layers; 1½ to two hours' time is sufficient to drive off nearly all the zinc, and the resulting bullion is comparatively clean. The product in the pans is not touched or stirred during the roasting and experiments have proved that mechanical losses are thereby eliminated. The size to which the product is broken is small enough to insure a good clean roast.

The roasted precipitate is placed in a No. 100 graphite crucible in a coke furnace together with five to seven pounds of flux composed of $\frac{2}{3}$ borax glass and $\frac{1}{3}$ sodium carbonate. Melting is usually completed in about 1½ hr., using 80 to 100 lb. of coke. The bar is poured into a bullion mold as it is not necessary to remelt. The resulting bullion is 950 to 970 fine. Bars have been made as high as 984 fine, but the average is as stated above.

Although the mill was built seven years ago it is kept in the best repair and is still up to date in most of its features. The machinery is driven by electricity throughout, using alternating current at 440 volts; a total of 104 hp. is used.

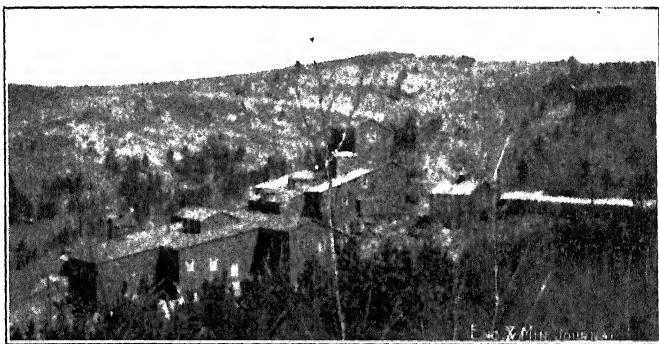
Other Mills in the District.—Among the mills now operating in the Black Hills district may be mentioned the new Reliance, which has just been remodeled and has started operation along lines unusual in the camp, treating slime by a continuous decantation process and making use of Dorr thickeners for the purpose. This mill has also installed a Portland continuous filter for filtering the slime tailing. The mill has been in operation only a short time, remodeling is not yet complete and no information is available for publication.

The Bismark Mining Co. is building a mill near the Wasp No. 2 in which the system of treatment will be identical with that of the latter. The mill is approaching completion and should be in operation in the near future.

In this paper no mention has been made of the metallurgy of the Homestake installations. This is a matter which is so extensive that it should be treated alone and I hope in a later paper to discuss that practice. The Homestake is treating ores on a scale which is not equaled at the present time and has attained an astonishingly low cost for mining and milling. An ore of low grade is being treated and the methods, original in many instances as they are efficient, are a lasting credit to the energy of the technical men who are responsible for their devising.

There are many mills in the Black Hills which are not now operating, but it would serve no useful purpose to speak of these at the present time in spite of the fact that some of them may resume operations in the near future.

Conclusions.—It is with no little hesitation that one ventures to call attention to details in the practice of this district which seem capable of improvement, in view of the fact that capable operators have studied the problems and undoubtedly are aware of the solutions of them even if they are not put into practice at the present time. A little criticism, however, may be helpful from a constructive point of view and the few suggestions that I venture to make are offered in a friendly spirit, with a

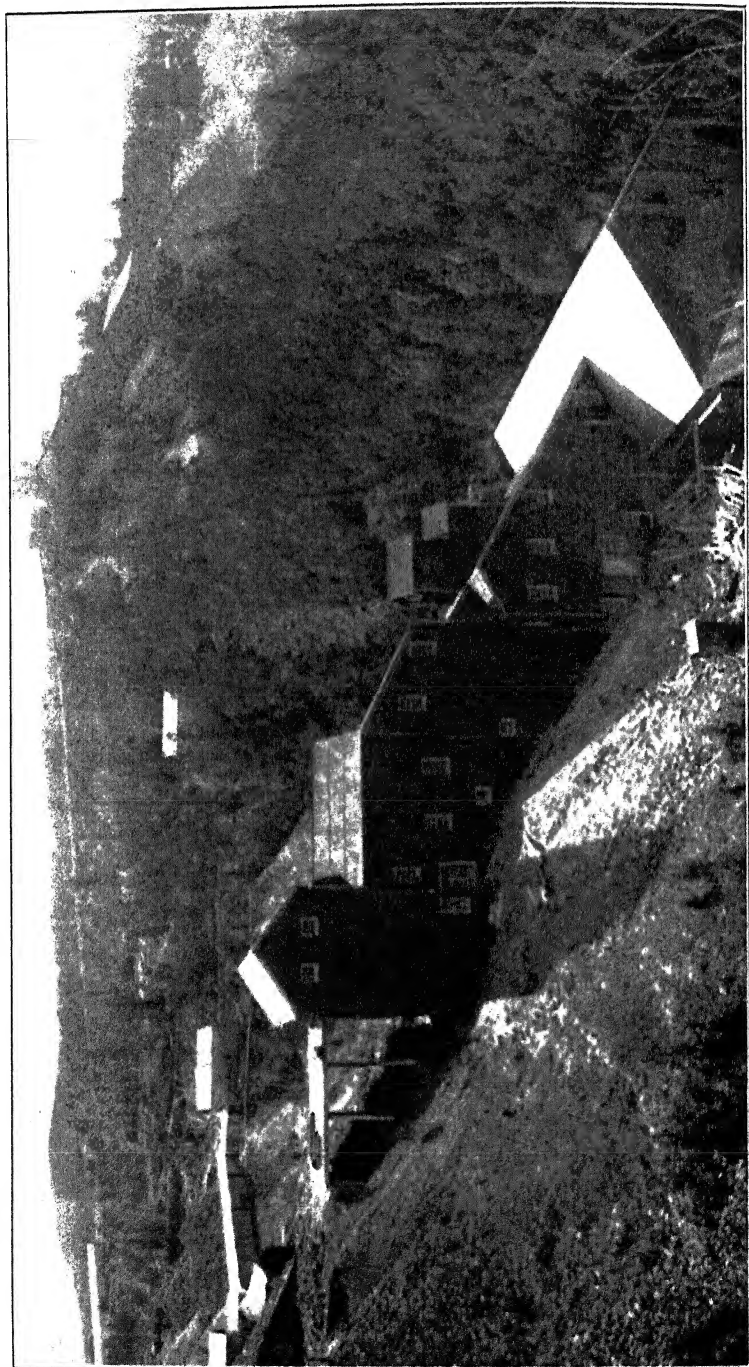


NEW RELIANCE MILL.

desire only to add a little to the present practice. It is possible that a perspective view may be appreciated by those whose vision has been limited by long contact and short focus.

The first impression is that in few of the operating plants is there any efficient means of estimating with accuracy the tonnage treated. The importance of the point will be readily appreciated by those familiar with the problem, so that it needs no discussion. It will be sufficient to say that mill estimations are not sufficiently accurate upon which to base comparative calculations except in such extraordinary cases as has already been mentioned in the Wasp No. 2 mill. A system of weighing the mill ore, while expensive to install, will repay, in information acquired and in satisfaction, any financial outlay which may be necessary.

The same is true of sampling. Sampling plants are expensive to install but are productive of much good. In some mills in the district samples of mill run are taken by means of a large elevator bucket fixed to a chain belt which periodically crosses the stream of ore falling into the mill bins. This device is more than likely to give erratic results. The area of the bucket opening is too small, and large pieces of ore strike the



NEW BISMARK MILL.



DEADWOOD, S. D., SHOWING HOMESTAKE SLIME PLANT IN CENTER BACKGROUND.

edges of the bucket and bounce off, leaving a sample which is not representative. Often the capacity of the bucket is not sufficient to hold the entire quantity of ore which belongs to it and it piles up and overflows, again resulting in an erratic sample. I believe it is recognized that to secure a proper sample it is necessary to take the whole stream of ore at regular intervals, the oftener the better, and to reduce the size of the sample by successive operations of the same kind. A part of the stream for all or part of the time is not sufficient and leads to a sample which is not accurate, and this, in the opinion of those who have most carefully studied the subject, is worse than no sample at all.

Crushing Hard Ore with Rolls.—The practice of crushing through rolls in this district should be an object lesson to some metallurgists who have maintained that rolls are not adaptable to hard ores. Some of the roll installations here are crushing extremely hard, close-grained ores and doing it efficiently and at low cost. The controversy as to the supremacy of rolls or stamps might receive considerable light if a thorough comparison of the different practices in the camp were made. The greatest difficulty is that only one company, the Homestake, is using stamps, and this is on such an enormous scale that the extremely low costs obtained there cannot be compared with those obtained by rolls on a much smaller scale. The Homestake mills are treating more than 4000 tons daily and by reason of the extent of the operation are able to institute economies which would be impossible in smaller plants, the largest of which treats but 500 tons daily. Comparison of results without a long period of study and analysis is obviously out of the question.

High-speed chilean mills are operated in a number of plants and are giving good results. I have for some time believed that the slow-speed mill is capable of giving more economical results and a comparison of the cost of these and the cost obtained by the slow-speed mills at the Minnesota mill would be of greatest interest. In view of the fact that the latter will probably begin operations soon I hope to see this comparison made.

The use of lime is accompanied by some losses which might possibly be avoided by some slight change of method. This is typified in the case of the Wasp No. 2 which has already been mentioned and a similar procedure is followed at some of the other mills. The use of lime should be carefully watched, as it has been clearly proved at the Homestake that excessive lime has a retarding effect on the solution of gold in the ores of the Black Hills.

On the ores in general it is said to be true that fine grinding increases extraction, and where the ores have sufficient value to justify additional expense it would seem to be good business to determine accurately at just what point grinding can be carried to return the maximum economical extraction.

CHAPTER VII

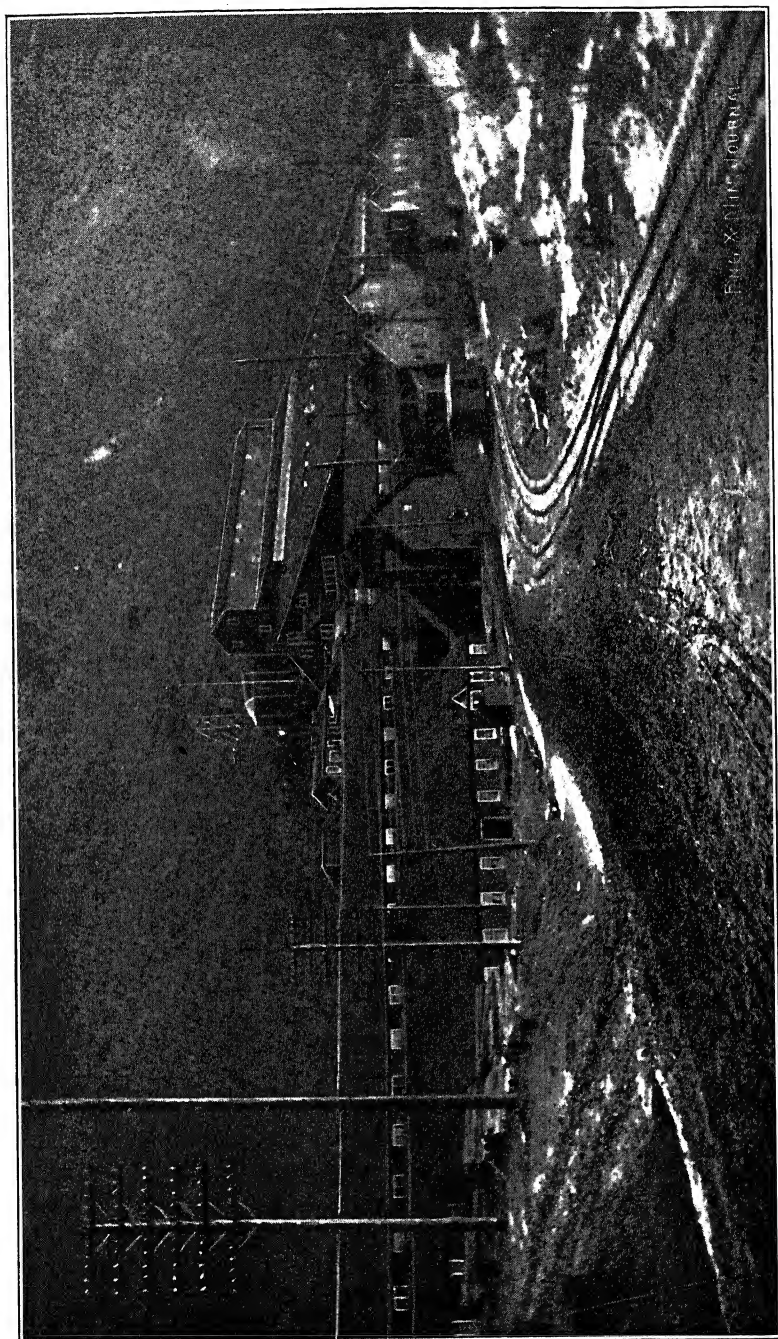
THE LIBERTY BELL MILL, TELLURIDE, COLORADO

The mill of the Liberty Bell Mining Co. is situated near the town of Telluride in San Miguel County, Colo. It is an old mill, operations having commenced in 1898 and continued up to the present time with only a few interruptions due to reconstruction and improvement of the plant and the unavoidable loss of time on account of labor troubles. The mill began operations with 10 stamps and the scale has gradually been increased until at present there are 80 stamps in operation, crushing a total of about 485 tons of ore per 24 hours.

Type of Ore.—The ore consists of quartz or calcite, banded, occurring either alone or together, and often having bunches of the feldspathic country rock. The vein material is generally fractured and contains large quantities of clay which produces a colloid slime in the milling process. The ore is not hard and milling is comparatively simple.

Cyanidation was early installed. In 1899 an experimental plant was built and tested and, success having been demonstrated, a 250-ton leaching plant was erected in 1900. It was soon shown that a substantial profit could be obtained by this method, although at that time it was about the lowest grade of ore being profitably handled by such process. Conditions were facilitated by the delivery of power from the plant of the Telluride Power Co., which had just begun operations. All these conditions aided in securing the satisfactory result which has been continuously improved upon up to the present time.

Ore Breaking.—The primary crushing plant is installed at the mine and consists of two 11×18-in. Blake sectional crushers. The ore is delivered above the crushers on to a grizzly having 3-in. openings. The pitch of the grizzly is steep, about 52°, in order to secure a satisfactory run of the ore, which is wet, averaging in general about 8% moisture. The crushers break the ore to the same approximate size as the product which has passed the grizzly, so that the material delivered to the mill is sufficiently small in one direction to pass the 3-in. opening. It should be noted, however, that this is a much different thing from passing a 3-in. ring, as material having one 3-in. dimension, no matter what its length and breadth may be, will go through the grizzly and large slabs of rock are frequently run into the mill.



LIBERTY BELL MILL AT TELLURIDE, COLO.

$1\frac{1}{2}$ miles long. The cableway crosses a high divide between the mine and mill, which necessitates a more substantial construction than when the whole line is on one approximate level. The highest point on the tramway is 1800 ft. higher than the mill. At the mill a steam-heated detention room is provided, which is useful in winter for thawing the buckets which have been loaded between shifts. Each bucket carries about 700 to 800 lb. of ore.

Amalgamation in Cyanide Solution.—There are 80 stamps of 850 lb. each in the mill, having a 7-in. drop and 106 drops per minute. Four of the five-stamp batteries are equipped with 12-mesh screen, due to a difference in construction, but the rest carry 14-mesh wire screen. The milling is done in cyanide solution carrying two pounds of KCN per ton. The sodium salt is used but the records are kept in terms of KCN as is customary practice at present.

In front of each five-stamp battery is placed a copper amalgamating plate, 4 ft. 7 in. wide and 8 ft. long, with a slope of $2\frac{1}{4}$ in. to each foot. Over this plate the pulp passes and is amalgamated. This detail is worthy of particular attention, as some authorities have maintained that amalgamation cannot be successfully carried out in cyanide solutions. It is done successfully at the Liberty Bell mill. Care and attention are essential to good results and a knowledge peculiar to this particular work must be obtained to operate it successfully.

The plates are maintained in a rather "wet" state, for if they are run fairly dry as is usual when milling in water, they soon become too hard and crusted to be of any use in recovering the gold. Keeping the plates wet avoids the excessive hardening of the amalgam and allows the retention of a large percentage of the gold. In view of the fact that some quicksilver and amalgam may be scoured off the plates while in this wet condition, traps are used to recover any particles which may escape. It is not claimed that the extraction under these conditions is as high as when the operation is carried out in water, but the object of the operation, which is the recovery of any coarse gold which might not readily dissolve in cyanide, is attained and the system has obvious advantages over milling in water where cyanidation is to follow.

When milling is done in water there is an appreciable amount of it introduced into the cyaniding system and it follows that an equal amount must be discharged with the residues.

It is almost impossible to get rid of the residual moisture without losing some cyanide and dissolved metal along with it. To avoid the discharge of excessive moisture with residues as far as possible is an important item in cutting down losses and by milling in cyanide solution, wherever it is possible, this discharge and its valuable content is saved to a large extent.

One development of milling in water, where that measure seems

unavoidable, is the system in use at the mill of the Smuggler-Union company, where the pulp delivered to the cyanide plant has previously been crushed and concentrated in water and contains an enormous preponderance of the liquid. This pulp is here thickened and then filtered, from which point it begins cyanide treatment containing a minimum of moisture. This is a system which cannot be generally recommended and its use in special cases will be considered later.

Classification and Concentration.—The pulp from the batteries is carried to Richards hindered-settling classifiers, which make a coarse, middling and fine product in addition to the slime overflow. The latter is taken to 6×6-ft. settling cones, the underflow of which is concentrated on Wilfley tables, the overflow going to Dorr thickeners.

The underflow product from the Richards classifiers is concentrated separately on Wilfley tables, the tailing going to an Akins classifier and the middling passing over a Bunker Hill screen which is fitted with 16-mesh No. 22 wire screen. The oversize from this screen also goes to the Akins classifier, the undersize being concentrated on a Wilfley table the tailing of which goes to the same classifier. The accompanying flow sheet gives the details of the pulp flow and machinery in operation.

The Akins classifier delivers the sand to a 5×22-ft. tube mill of the Abbé tire type, the mill feed containing about 40% moisture. The discharge from this mill is raised to a diaphragm cone where a separation is made, the overflow going to a simple cone and the underflow from both of them going to a second tube mill identical with the first one mentioned. The overflow from the simple cone, together with the product of the second tube mill, is elevated to a second series of amalgamating plates, and from the plates to cones, the underflow being led to Deister slime concentrators and the overflow to Dorr thickeners. Kidney pulp distributors are largely used in the mill. These machines have already been described.¹

The tube mills are of the tire type, which is convenient in allowing any desired size of inflow and outflow openings. In some cases mills of this type have proved more or less unsatisfactory, due to difficulty in keeping the tires running true on the supporting rollers, but here this difficulty has been overcome by careful installation on heavy, rigid concrete blocks and the use of a deep flange. No difficulty is now experienced and the mills run true and without vibration.

The mills are lined with siliceous blocks four inches thick set on edge. The lining lasts from nine to ten months without renewal and the type has been found generally satisfactory. In order, however, to take advantage of any economy which might be available, experiments are now being made with a lining of the Komata type, but as yet this work

¹ Eng. and Min. Journ., Nov. 26, 1910, p. 1046.

has not been carried far enough to give any conclusive results. Danish pebbles are used in the mills, about 130 lb. per mill per day being the consumption. The mills require about 43 hp. to keep them moving. The feeders are of the usual spiral-dip type.

There are three of these mills installed, but only two are in regular use, the third being held in reserve. This reserve mill is so arranged that it can be used in place of either of the other mills when one is cut out for relining or repair.

Agitation of the Slime.—The Dorr thickeners deliver a pulp thickened to about 2 : 1 to the Hendryx agitators, of which there are six. The pulp flow is continuous through the Dorr thickeners and the agitators, delivering continuously into the equalizer tank which feeds the filter. The agitators were originally installed to take advantage of the Hendryx specialties in cyanide metallurgy, but these having been found of questionable value, were abandoned and the tanks retained simply as agitators. They agitate by elevating the material in a central tube in the tank by means of a propeller screw. The system is considered expensive of power consuming 7 hp. each for the tanks, which hold about 33 tons of dry slime.

Grinding Requirements.—Due to the soft and clayey character of the ore, extremely fine grinding is not necessary. The statement would probably be more accurate were it said that grinding the ore through an 80-mesh screen is sufficient to reduce it to such fineness that it may be treated as slime. The battery grinding alone produces a pulp of the following analysis: On 20 mesh, 2.9%; on 40 mesh, 20%; on 60 mesh, 10.6%; on 80 mesh, 7.3%; on 100 mesh, 5.6%; on 200 mesh, 7.6% and through 200 mesh, 46.6%. After regrinding, the pulp which is subjected to agitation treatment has the following analysis: On 80 mesh 7.5%; on 100 mesh, 4.9%; on 200 mesh, 14.2% and through 200 mesh, 73.4%.

The pulp is easy to keep in suspension and is sufficiently fine to give the maximum economical extraction. The pulp as treated contains about 30% of colloid slime and one of the principal problems is the handling of the product and inducing settlement. In order to promote satisfactory settlement a milk of lime is prepared and added to the inflow to the Dorr thickeners, an average of seven or eight pounds per ton of ore being required. The average specific gravity of the dry slime is about 2.68, a figure which indicates no extreme either way, but about an average ore density.

Filtering the Slime Pulp.—The Moore filter plant is one of the earliest examples. The tanks are of wooden construction, but are well put together and are still in good condition. For filtering there are four baskets of 66 leaves each, the leaves measuring 6×8 ft. These baskets are operated in two groups of three tanks each, the middle tank being the one in which

loading is carried out and the others used for washes and discharging. The cycle is as follows: Loading, 50 min.; drying and transferring, 10 min.; washing, strong solution, 15 min.; washing, weak solution, 30 min.; discharging, 10 min.; transferring, five minutes.

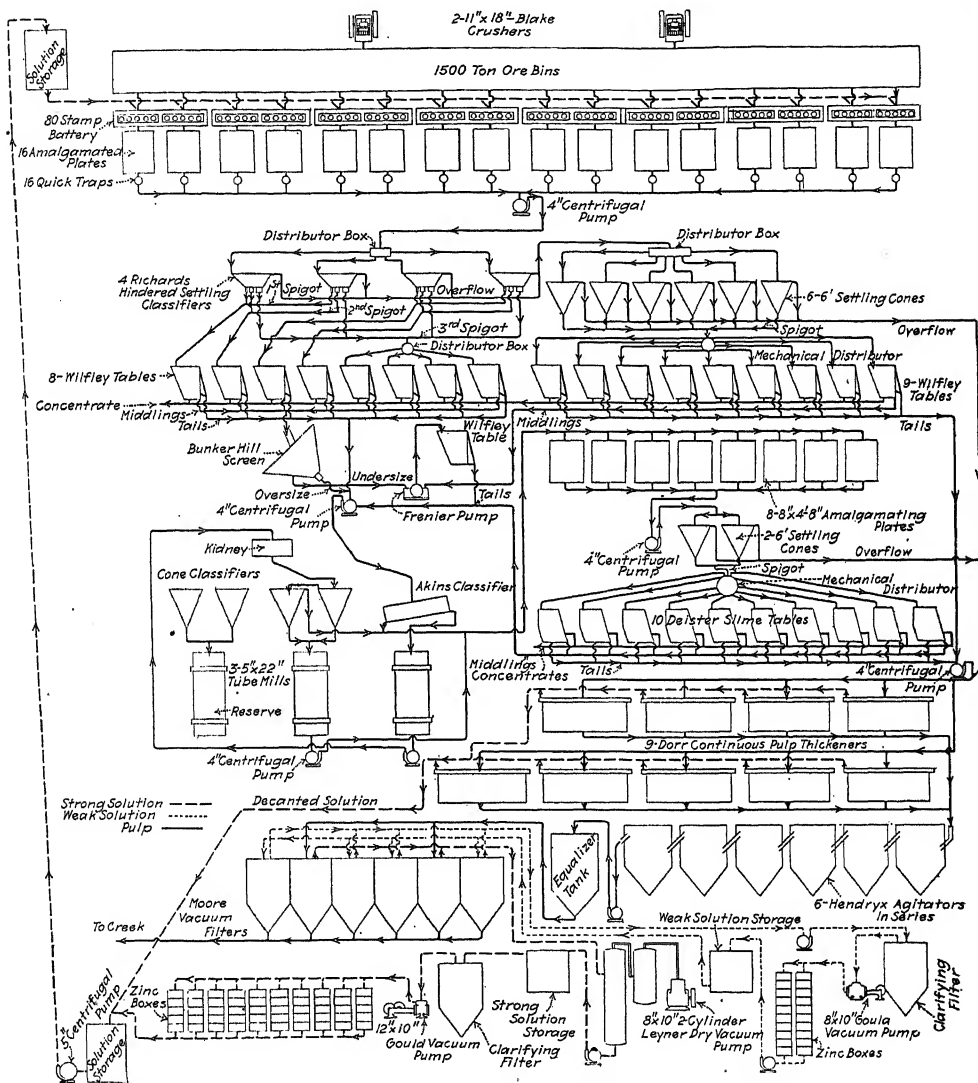


DIAGRAM OF TREATMENT AT LIBERTY BELL MILL.

The thickness of the cake made varies from seven-eighths to one inch, approximating 10 tons per basket of dry slime. The plant was constructed to treat a much smaller tonnage than is now being put through

it, but has been forced up to its present capacity by increasing the efficiency of each operation. One of the refinements is the installation of a vacuum pump of high efficiency to expedite the filtering. This machine is of the type usually used for obtaining a vacuum in the manufacture of incandescent electric lamps. The system is a dry-vacuum operation, no solution passing through the vacuum pump. The solution discharge is into a specially constructed deep pit for securing a barometric discharge.

The loss in dissolved metal amounts to about three cents per ton of dry ore and the cyanide mechanically lost to about 0.3 lb. per ton. The filtered pulp has an average dilution of 2:1 and air lifts are used to assist in maintaining an even consistency vertically in the tank. The solids do not settle rapidly, as has already been mentioned, but the air lifts are used as an additional assurance of homogeneity. Solution under 18 lb. pressure is used for discharging the cake and the operation is concluded with air under 10 lb. pressure.

The filter leaves require acid treatment about every three months, and to facilitate this operation without delay of filtration, a separate basket is always kept in readiness for instant use. The basket requiring acid treatment is removed from service and the extra one immediately put into action. A separate tank is provided for containing HCl for treating the leaves, and the cost of the acid-treating operation mounts to about 0.6 c. per ton of ore.

Precipitation is accomplished by means of zinc shavings, using boxes of the ordinary type. It is recognized that the use of zinc dust offers conveniences and in many cases economics, but the question has been given careful study here without seeming to justify a change of system.

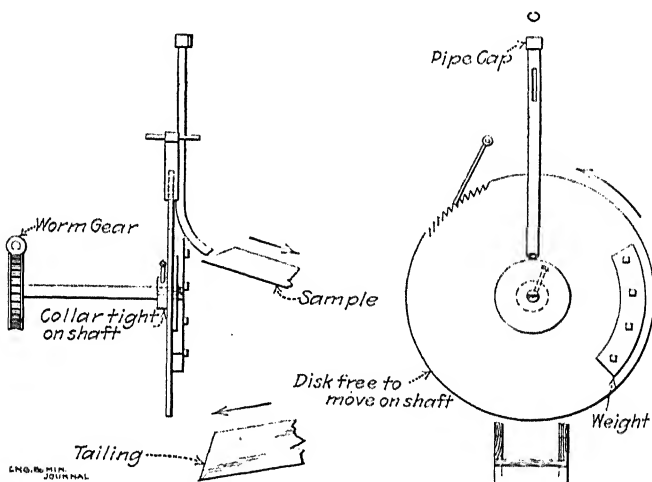
The precipitation at the Liberty Bell mill gives no trouble in any way, the only requirement being that the clarified solution be allowed to pass over the zinc at the stated rate of about 0.7 ton per cu. ft. of zinc shaving per 24 hr. Precipitation is good, head solutions carrying \$1 per ton give tailing assays of one to two cents per ton. The solution going into the pregnant-solution tanks is metered by the use of a device similar to that described in the article on the Hollinger mill at Porcupine, Ontario.

The precipitate is melted in oil-fired tilting furnaces, one Steele-Harvey and one Donaldson furnace being installed. The operation is extremely simple and presents no difficulties. The precipitate is lightly acid treated, fluxed and melted, the bullion obtained averaging over 900 fine.

A small blast furnace is used for cleaning up all waste product such as flue dust, slag, sweepings, etc. This material is all briquetted with portland cement in such proportion that a satisfactory slag will result and periodical runs are made which eliminate all waste products. The results are altogether satisfactory, there being a substantial saving over selling such material to the smelters.

Use of Heated Solutions.—The heating of solutions has been found of assistance in the mill. This measure was adopted primarily for the purpose of bringing extractions up to the normal point in cold weather, but it was considered advisable to continue to warm the solutions throughout the year in order to take advantage of the additional recovery of the silver. The effect upon the gold is not noticeable.

The matter of warming solutions is one that has received some attention from metallurgists in various countries and in many cases has not shown any particular benefits. At any rate there has been no consistency in the results obtained. The silver mills in Mexico, particularly, have experimented with solutions of various temperatures and generally speaking the improvement has been so small and variable that benefits have been considered not proven. In case of the Liberty Bell, the action



AUTOMATIC TAILING SAMPLER AT LIBERTY BELL MILL.

of the warm solution has not been studied for sufficient time to warrant final conclusions. The benefit, if any, may not be confined to the dissolving effect of the solutions but may extend to the amalgamation and concentration, as will be mentioned later.

The ore delivered to the mill is not regularly sampled nor weighed. In order to approximate the weight, a number of the tram-way buckets are weighed each day and the total weight of ore delivered is calculated from this information, together with the number of buckets coming into the mill. The latter are counted automatically by means of an electrical device which records each bucket as it enters the mill, the counter being installed in the mill office. No sample is taken of the ore, the average content being obtained by summing the total mill production and the

content of the tailing leaving the mill. The latter is sampled automatically by a device invented and perfected by W. E. Tracy, mill superintendent. The sampler has been described before¹ but a sketch of it is herewith presented as it is worthy of note.

It consists of a disk mounted on a shaft and moved by means of a worm gear. A pipe is fixed to the disk, the pipe having a slot through which the sample enters. The worm gear moves the disk slowly until a point is reached where the weight fixed to the disk over-balances the pipe and the disk swings around rapidly, the slot in the pipe passing the tailing stream and taking a sample of it. The momentum is sufficient to carry the disk far enough to raise the pipe into a vertical position again and the sample runs out of the curved end of the sampling pipe into a small launder which is properly placed to receive it and conduct it into the sample receptacle. The movement is so rapid that the solids in the sample do not settle and the pipe drains cleanly. A pawl engaging a ratchet cut in the disk prevents a return swing of the disk.

This system of estimation of ore content cannot be recommended at all times. It may be fairly satisfactory if every care is taken to avoid mishaps and losses within the mill, but its great weakness is that such losses and shortages of production cannot be readily detected.

CHEMICAL CONSUMPTION AND COST AT LIBERTY BELL MILL

Material	Consumption per ton ore lb.	Cost	Unit
Zinc.....	0.5	\$0.115	lb.
Lime.....	7-8	0.005	lb.
Cyanide (KCN).....	1.3	0.215	lb.
Litharge.....	0.3	0.085	lb.
Pebbles.....	0.54	37.75	ton.

The period of agitation which the pulp receives in the mill is about 14 hr. in the mill circulation and about 12 hr. in the Hendryx tanks. The consumption of chemicals and the cost per unit is about as given in the accompanying table.

Metallurgy of the Ores.—The metallurgy of the Liberty Bell ore is not complicated, as there is no rebellious element to be reckoned with. The fact that silver exists in sufficient quantity to make its extraction an object introduces an element which is somewhat more complicated than when only gold is to be extracted. In this case, however, the quantity of silver is small and strong solutions do not have to be resorted to. A 2-lb. KCN solution is used throughout the mill. The use of a lead salt, however, has been found advantageous. At first lead acetate was used, added to the

¹ Trans. A. I. M. E., October, 1911.

agitators, but now litharge is in regular use, the addition being made to the tube mills where it is readily ground up and put into solution.

The thorough system of concentration used is based upon the belief that it does not pay to attempt to extract the contents of the sulphides in contact with the remainder of the ore as the strong solution required and the long time would entail a loss of cyanide and cost of agitation out of proportion with the recovery. By removing the sulphides the siliceous ore may be treated, as has been shown, with weak solutions and short time of agitation and the sulphides may be handled in some satisfactory way.

Up to the present the sulphides have been sold to the smelters, but experiments are under way looking toward a cyanidation of the product on the ground. While these experiments have not been carried to conclusion, it may be said that the indications are that the process is feasible, and if this is true an additional saving will be made possible. The idea is to treat the concentrate in a separate system using stronger solutions and more time. The residues from the concentrate treatment will be thrown in with the regular siliceous ore and will thus be given an additional treatment, with the possibility that the total recovery, compared with its cost, will show a greater profit than the method now followed will produce.

Special Metallurgical Features. The two special metallurgical features, as have been described, are first, amalgamation on plates in cyanide solutions, and second, the heating of mill solutions in order to increase extraction of silver.

PERCENTAGE EXTRACTION AT LIBERTY BELL MILL DURING FISCAL YEAR 1912

Gold	First half	Second half
Amalgamation.....	48.98	50.20
Cyanidation.....	35.71	34.40
Concentration.....	7.52	8.40
Total.....	92.21	93.00
<hr/>		
Silver		
Amalgamation.....	7.12	11.30
Cyanidation.....	37.67	39.70
Concentration.....	17.24	21.60
Total.....	62.03	72.60

The first of these items is one that has been called unsuccessful and impossible in many cases, but it has here demonstrated its value, and there can be no reasonable doubt that it is useful in some cases. I should

consider it a valuable system to adopt in cases where amalgamation was considered essential for the purpose of recovering coarse gold which would not dissolve in cyanide solutions in any reasonable length of time, and which existed in such large quantities that the regrinding process would not reduce it to some form readily dissolved. It should be preferable to milling in water, which has manifest disadvantages.

Extraction and Cost.—Due to certain changes which took place in about the middle of the present fiscal year and the changes in mill results which followed, the ore content and recovery are given as types for these periods. The ore content for the first half of the year was 0.27 oz. of gold and three ounces of silver; for the second half, 0.27 oz. of gold and two ounces of silver.

TABLE I. LIBERTY BELL MILLING COSTS

	Labor	Supplies
General mill labor.....	\$0.0901	\$0.5811
Crushing.....	0.0531	0.0194
Stamping.....	0.0935	0.0973
Regrinding.....	0.0104	0.0665
Settling and agitating.....	0.0150	0.0390
Filtering.....	0.0372	0.0509
Concentrating.....	0.0476	0.0199
Amalgamating.....	0.0426	0.0224
Precipitating.....	0.0137	0.0755
Total labor.....	0.4032	Total 0.9720
Total supplies.....	0.9720	
Total cost.....	1.3752	
Depreciation.....	0.1200	
Realization.....	0.3100	
Total mill cost of production.....	1.8052	

The increase in silver extraction in the second half is noteworthy in view of the fact that the ore content is one-third less, a situation which is opposed to general experience. There are two factors which have changed, either of which, or both, may be in part or wholly responsible for the difference in results. The first change, the mining of the ore from a different and deeper level, may have its effect, and the second change, the increase in solution temperature, would naturally influence results to some extent.

Of a total gain of 10.57% only 2.03% is due to improved recovery in the cyanide solution. The coincident alteration of two important factors makes it impossible to say without further study just what part each has played in producing the final result. The temperature of the solution in agitators and filter plant has been raised to about 80° F. and that on plates,

concentrators and settlers to about 70°. The cost of operation, based on the milling of 104,460 tons in seven months, is shown in the accompanying tables.

TABLE II. DISTRIBUTION OF GENERAL EXPENSES AT LIBERTY BELL MILL.

Labor	Per ton	Supplies	Per ton
Superintendence.....	\$0.0268	Pipe lines.....	\$0.0061 ¹
Heating.....	0.0129	Bins.....	0.0085 ¹
Electric plant.....	0.0106	Building.....	0.0628 ¹
Lubrication.....	0.0034	Electric plant.....	0.0111
Pumping plant.....	0.0212	Pumping plant.....	0.0198
Watchman.....	0.0083	Fuel and heating.....	0.0471
Examination and tests.....	0.0068	Tools.....	0.0043 ¹
		Cyanide.....	0.2614 ¹
	0.0901	Lime.....	0.0426 ¹
		Lead salts.....	0.0330
		Light and power.....	0.0378 ²
		Oil and waste.....	0.0091
		Assaying and melting.....	0.0347 ¹
		Examination and tests.....	0.0027
		Miscellaneous.....	0.0001
			0.5811

¹ Combined labor and supply.

² The power in this item is that used in pumping between departments.

CHAPTER VIII

PRACTICE AT CRIPPLE CREEK, COLORADO

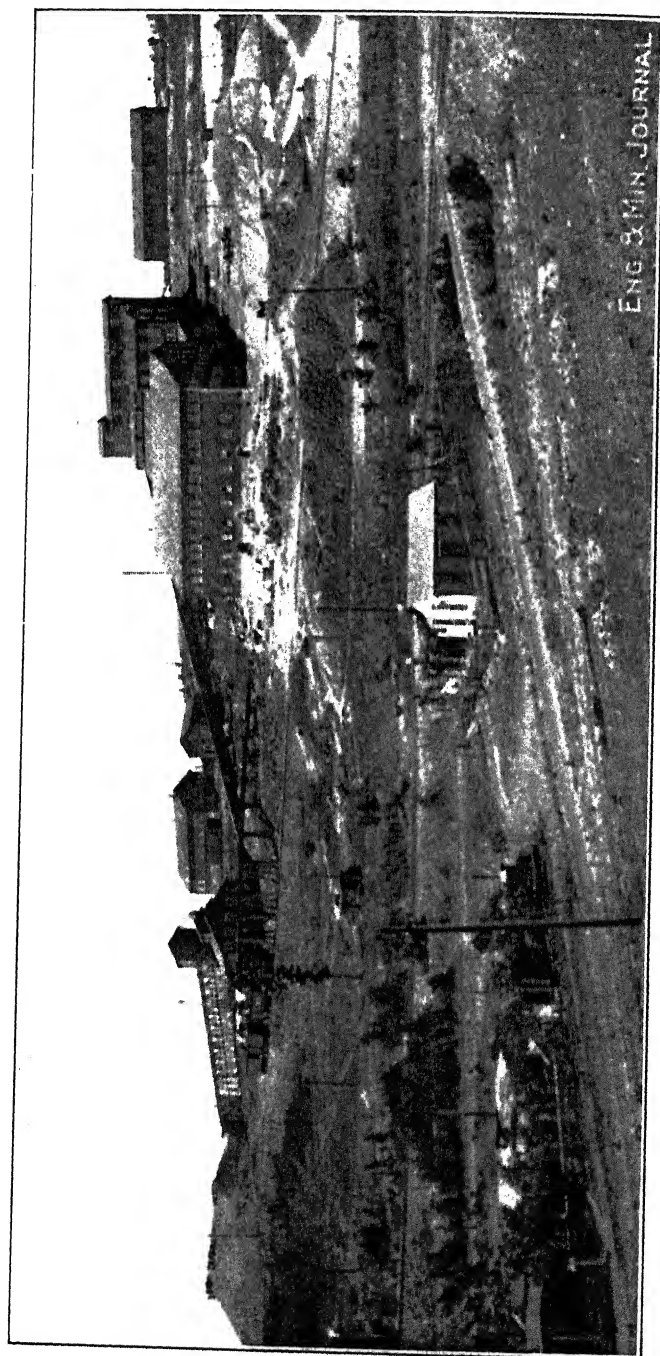
The Cripple Creek district of Colorado is one of the most famous gold camps of the world and has, at times, been called the richest gold district in existence. Although this can hardly be said to be true at present, still the district is of great importance and continues to produce gold in large quantities. Its minerals are too well known to require any detailed description at the present time. The occurrence of tellurides of gold is distinguishing and is the principal feature which opposes simple reduction methods.

The metallurgy of the ores of the district has passed through all the changes common to most of the gold camps of the United States, plate amalgamation, chlorination, concentration and finally cyanidation having been applied to the minerals with varying degrees of success, not to mention the procession of patented and secret processes which have made one brief appearance and then vanished forever. At the present time cyanidation, occasionally alone but more generally in combination with concentration or some other metallurgical means, notably roasting, is applied to all the ores which are too low grade to smelt, and the process has become essential to the life of the district.

Many Mills in Operation.—There are a number of mills at work in the district and in addition to these a quantity of ore is shipped to the two large custom mills operating at Colorado Springs. The richer ores are smelted but the quantity of this product is not so important as it was in earlier days. By far the greater quantity of ore is milled and the cyanide process is responsible for the recovery of a large part of the gold.

Most of the mills in the district, or at any rate the most important ones, use a combination of concentration and cyanidation, the idea being to remove, as far as possible, the tellurides, sulphides and other refractory compounds which do not yield readily to cyanide treatment, leaving a tailing which is satisfactorily treated with cyanide solutions of low strength and at reasonable cost. Some of the plants are simple leaching installations treating ore or waste of low grade and in different degrees of fineness, but these present no metallurgical novelties and are simply efforts to extract a profit from material available without reference to technical niceties or conservation of resources.

Of the more important mills which are following modern practice and obtaining results which are satisfactory in various degrees, may be men-



PORTLAND CYANIDE MILL, AT VICTOR, COLO.

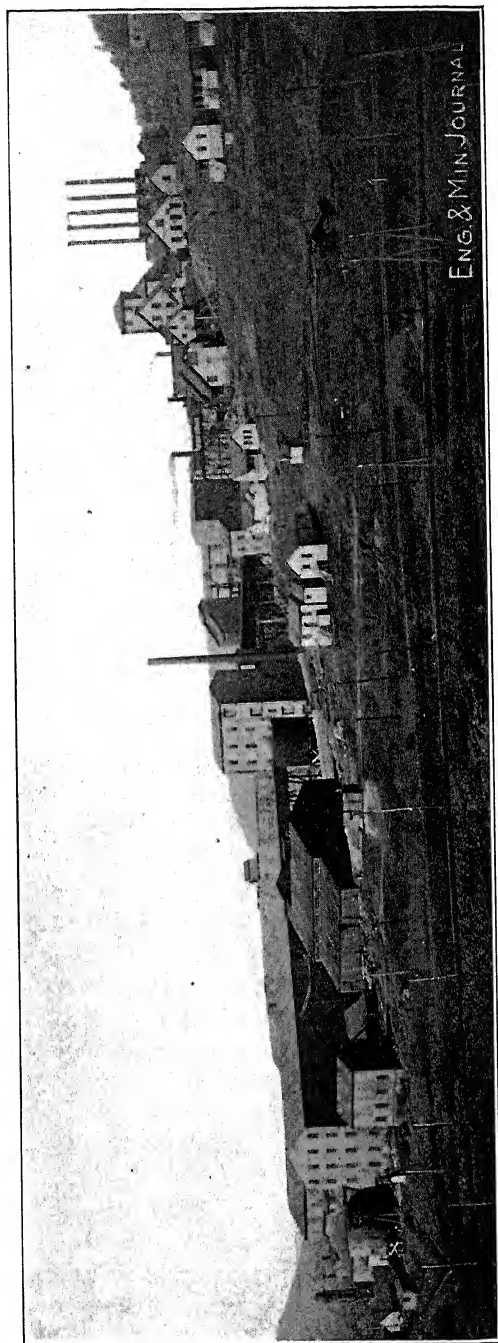
tioned those of Stratton's Independence, Ltd., the Portland Gold Mining Co., the Ajax-Colburn and the Blue Flag Mining Co. Of these the Ajax is the principal one which has made serious attempts to obviate the use of both concentration and roasting and use the cyanide process direct, making use of chemical means in combination with the cyanide solutions to dissolve the refractory gold compounds. This mill has installed the Clancy electrochemical method of procedure and is now in process of ascertaining what benefits may be expected from it. At present there is not sufficient information available to enable a statement which will definitely prove either success or failure for the system, but it is hoped that within a few months data for the settlement of the question may be forthcoming. The serious attempt of the operators of this plant to solve a difficult problem along scientific lines is worthy of the complete success that they hope to obtain.

Separate Dry Crushing at Ajax.—The Ajax has installed a plant entirely separate from its cyanide mill in which the ore is crushed dry and mechanically sampled. The ore is brought into this plant in electrically moved cars and is passed through a series of crushers, rolls, screens, etc., being sampled during the process, and is finally delivered in a condition sufficiently fine to be mixed with the cyanide solutions and classified, any oversize being led directly into the tube mills for regrinding. This, I believe, is the first attempt in the Cripple Creek region to slime all the milling ore and treat it directly by cyanide. The statement of proven results will be awaited with interest.

The Blue Flag mill is another which is making a trial of a comparatively new development of cyanidation. It is equipped with machinery for the continuous-decantation process using Dorr thickeners in conjunction with agitation tanks of a well-known design. This process presents some innovations which are of great interest at this time and will be discussed in a separate article.

Portland and Independence Mills.—The mills of the Portland Gold Mining Co. and Stratton's Independence, Ltd., are similar in many ways, the principal difference being that the Portland makes a total slime product, while at the Independence the sand and slime are treated separately. Due to the fact that the Portland company does not desire to make public any details of its practice at the present time, no information can be given, but it will be safe to accept the practice followed at the Independence as typical of successful work in the Cripple Creek district and its system, which is made public without reserve, will form the bulk of this article.

At this mill a long series of experiments was conducted by Philip Argall and it was decided that the most feasible method was careful concentration of the ores followed by cyanidation of the tailing. The adaptability of this system was due to the fact that the ore contained a quan-



MINE AND MILL OF STRATTON'S INDEPENDENCE, LTD., VICTOR, COLO.

tity of gold in the form of telluride which is not easily cyanied by direct methods and it was considered advisable to remove this constituent and extract its gold content by some means more satisfactory. A mill to treat 5000 tons per month was erected to make use of this method. The mill was afterward increased to handle 10,000 tons per month, at which capacity it is now operating.

The ore supply comes mainly from the dumps, a large accumulation of this material having resulted during the long life of the mine. The average content has a value of about \$3.50 per ton as milled. An electric shovel is used for moving the material, which is loaded into 4-ton cars, hoisted up an inclined plane and delivered into the crusher house.

COSTS AT STRATTON'S INDEPENDENCE MILL

	Per ton treated
Dump breaker:	
Power.....	\$0.0436
Operation.....	0.0516
Repairs.....	0.0681
Total.....	\$0.1633
Crushing and concentrating:	
Power.....	0.1946
Operation.....	0.1192
Repairs.....	0.1982
Loading concentrate.....	0.0097
Total.....	0.5217
Cyaniding:	
Power.....	0.0484
Operation.....	0.3420
Repairs.....	0.0549
Total.....	0.4453
Miscellaneous:	
Heating.....	0.0050
Water service.....	0.0048
Liability insurance.....	0.0057
Fire insurance.....	0.0298
Taxes.....	0.0465
Total.....	0.0918
Mine breaker ¹	0.0169
Total cost.....	\$1.2390

¹ The mill receives one-tenth of its supply from a small breaker plant where mine ore is crushed to $\frac{1}{2}$ in. and taken directly to the chilean mills.

From the head of the crusher house the ore is delivered to a No. 7½ Gates gyratory crusher, which delivers its crushed product to a picking belt three feet wide. Here the larger boulders of barren rock are thrown out as much as possible and the belt carries the remaining material to a No. 5 Gates crusher, in which the ore is reduced to about 1 ½-in. cubes and conveyed, by means of an 18-in. conveying belt, to the steel storage bin. The sorting does not materially increase the value of the ore, less than 3% being removed in the process, which is of more importance on account of the quantity of pieces of wood, steel and much other foreign matter which comes from the dump.

The steel mill bin is of special design and was installed with the idea of obviating blocking or sticking of the ore, which object has been attained. It consists of a steel cylinder, the bin proper, terminating in a cone-shaped bottom. The apex of the cone is cut off leaving a circular opening four feet in diameter. This opening is set down into another smaller cone, the feed cone, which has a 12-in. opening delivering the ore to a revolving disk feeder. The opening in the bin bottom is large enough to prevent blocking and is small enough to relieve the feed cone of excessive pressure. The device works successfully and the bin can be entirely emptied of its contents without shoveling. The ore stored in the bin is all reduced to smaller than 2-in. cubes.

From the storage bin the ore is fed through two sets of 16×36-in. rolls which reduce it to about ¼-in. size. Due, however, to the flaky character of the ore, largely phonolite, the size is more nearly ⅜ in., although its thickness is generally less than ¼ in.

Addition of Lime.—The ore coming from the storage bin is slightly moistened with cyanide solution which tends to settle the dust and also to slake the lime which is added at this point. By means of this procedure it is calculated that the lime shall be in good condition to render effective service, and by the passage through the rolls normal character of ore feed, they crush almost exactly five tons per hour with an expenditure of 55 hp. With the mill in average condition the pulp delivered from it has the following approximate composition: On 50 mesh, 21%; on 100 mesh, 12%; on 150 mesh, 5%; through 150 mesh, 62 per cent.

The total steel consumed per ton of ore milled, using Midvale or Latrobe brands, amounts to 0.62 lb. The crushing pressure of the mill amounts to about 900 lb. per sq. in., which is probably somewhat increased by centrifugal force.

The Chilean mill has been generally considered a sliming machine, but the operators at the Independence mill have found that within certain limits it is able to give a fine, yet granular product. The adjustment, however, must be made with a view to the result desired. In some cases, of which the Independence is typical, a fine, granular product is desired

for concentration efficiency, while in other instances, typified by the total-sliming mills, the highest economy is secured by producing an extremely fine product as quickly and simply as possible. In the latter case the chilean mill has been able to prove its adaptability, and when construction includes the Mantey offset I should be inclined to consider the large diameter, slow-speed mill both cheaper and more efficient than the higher-speed mills such as are used at the Independence. In connection with this subject it will be interesting to refer to my article on chilean mills¹ and also the paper by Walter H. Urbiter² on the same subject.

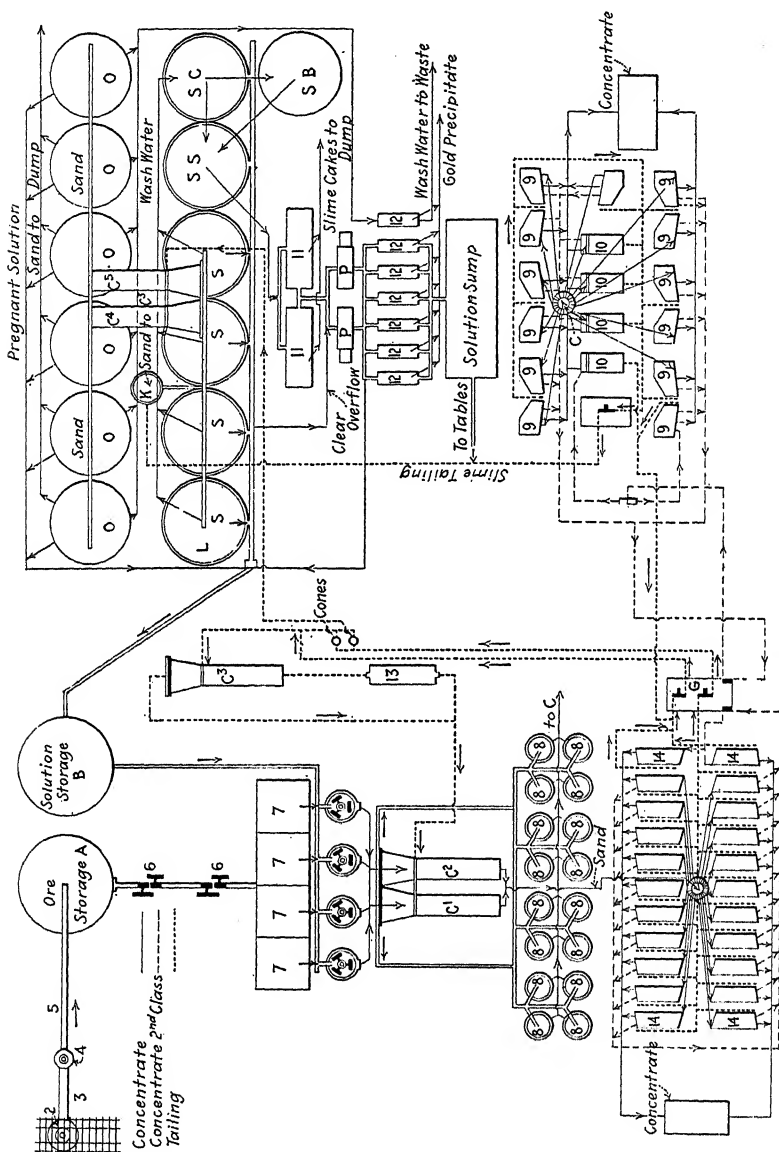
The ore coming from the storage bin is slightly moistened with cyanide solution which tends to settle the dust and also to slake the lime which is added at this point. By means of this procedure it is calculated that the lime shall be in good condition to render effective service, and by the passage through the rolls becomes thoroughly mixed in with the ore and probably reaches every part of it. Being in a damp condition, the time of passage through the rolls to the mill bins and the time it remains in the latter should be sufficient for a thorough neutralization of any latent or developed acidity in the ore. The system of adding lime to ores in cyanide milling has been the subject of much discussion and the methods used are extremely varied. It is of considerable interest to note the methods and reasons adopted at the different plants, and a final comparison of them will be valuable and of technical interest.

Chilean Mills for Fine Crushing.—From the rolls the ore is taken to the storage bins above the chilean mills, which are used for fine crushing. The fine-crushing plant consists of four 6-ft. Akron chilean mills. Three of these are kept in operation all the time, easily crushing the required amount of 10,000 tons per month, the third being held in reserve and ready for use at any time. The mills can each crush from 100 to 130 tons per day, according to the feed they receive. The ore is fed into them by means of revolving-disk feeders which may be adjusted to any required capacity.

The mills are fitted with square wire screen having 0.046-in. aperture and 0.054-in. wire. The speed is about 33 r.p.m., and with this adjustment, using the normal character of ore feed, they crush almost exactly five tons per hour with an expenditure of 55 hp. With the mill in average condition the pulp delivered from it has the following approximate composition: On 50 mesh, 21%; on 100 mesh, 12%; on 150 mesh, 5%; through 150 mesh, 62 per cent.

The total steel consumed per ton of ore milled, using Midvale or Latrobe brands, amounts to 0.62 lb. The crushing pressure of the mill amounts to about 900 lb. per sq. in., which is probably somewhat increased by centrifugal force.

Concentration a Feature.—From the Chilean mill the pulp is led to the Ovoca classifiers, which are double spiral-screw machines designed by Philip Argall. The milling is done in cyanide solution containing $\frac{1}{2}$ lb.



TREATMENT DIAGRAM OF STRATTON'S INDEPENDENCE MILL.

KCN per ton, and from that point the ore is constantly in solution. The Ovoca classifiers give a sand practically free from slime with from 15 to 25% moisture, thus performing the operations of separation and sand

dewatering. The sand is sent to 20 Card concentrators. There are 22 installed and the pulp is distributed to the tables by means of an automatic distributor which has been perfected in use at this mill.

The slime from the classifier is thickened in cones and sent to the slime concentration department, which is equipped with 13 Deister tables and four vanners. The Deister slime concentrator here performs equally as good work as the vanners and the maintenance expense is less than one-tenth of that of the vanners.

From the sand concentrators two products are obtained, a high-grade concentrate, which is shipped direct, and a middling, which is reground and reconcentrated. Originally it was designed to treat the concentrate on the ground and a roasting plant for that purpose was erected, but it was finally decided, on account of the character of the concentrate, which is desired by the smelters, to ship it. The concentrate can now be considered as having its gold content definitely recovered as the other elements contained pay all its expenses, leaving the gold net. Under such circumstances it would not be wise to attempt its local treatment.

High Value of Finer Material.—In the case of the Independence ores it is invariably true that the finest material carries the most gold. The gold occurs mainly in films along the fracture planes or in small cavities, the sulphide in the body of the rock being of low grade and often worthless. It is due to these basic facts that the crushing system in use was devised and followed, it being briefly an attempt to liberate the sulphotellurides to sufficient extent that they might be removed by concentration, leaving a sand tailing of low grade that might be lightly cyanided and discarded.

The slime, containing the higher value, is also concentrated as closely as possible and cyanided carefully by more efficient methods. The slime tailing has never been reduced as low as the sand. The guide now chosen is to keep the sand tailing below \$1 per ton in value, making a slime that runs in the neighborhood of \$2 per ton after concentration. The coarse sand produces a high-grade concentrate, running from five to seven ounces per ton, a middling which is reground, in turn producing rich concentrate and a proportion of slime, and a tailing of extremely low gold content, as has been mentioned. This procedure enables the comparatively coarse crushing to be practised in the Chilean mills and renders obtainable a crushing cost which would be out of the question were total sliming resorted to.

Sand Leaching.—The sand and slime tailings are both pumped to the cyanide plant where a pair of Ovoca classifiers separate them finally, the sand being moved by a special conveyor into the sand-leaching tanks. This conveyor is the usual "grasshopper" type, a long bar, supported on wheeled trucks, having a number of hinged pusher blades working in a

trough or launder. The launder is arranged so that openings can be made into each tank at several different places. The sand is distributed practically automatically, the final leveling of the top of the tank being about the only hand labor required. A stream of solution is led into the tank along with the sand, which is so free from slime that no trouble with channeling or segregation of slime is experienced.

The sand thus laid into the tanks is treated with $\frac{1}{2}$ -lb. cyanide solution for four days and is then sluiced out and run to waste. The sand treatment is extremely simple; but since the precious-metal content is small, the economical maximum of extraction is reached in this way.

Bromocyanidation of Slime.—The separated slime from all departments is led into four continuous thickening tanks, the products being a clear overflow and a thick slime which is pumped into a treatment tank where it receives a six-hour treatment with $\frac{3}{4}$ -lb. cyanide solution, and afterward a four-hour treatment with bromocyanide in a separate tank. The bromocyanide treatment is in accordance with the general practice, the solvent being made from the usual "miners salt" in the ordinary way. The only departure from generally accepted practice is that it is found necessary to maintain a comparatively high alkalinity during the treatment, general practice insisting on a neutral solution in most cases.

The tanks used for agitation are a special design, the features of which are a pointed cone bottom and a cylindrical section of little height, a central agitation pipe, into which air is admitted at the bottom, and having a cone over its outlet, which is in about the middle of the vertical height of the tank. The cone is open, with its vertex pointed down and is designed to spread the outcoming pulp over the area of the tank. It is simply another method of taking advantage of pneumatic agitation, the variations of which are without number. The accompanying flow sheet shows the movement of pulp and solution and the machinery installed. There is little novelty in the methods used in cyaniding the concentrate tailing.

The pulp is fed from a storage tank into a vacuum filter of the stationary or Butters type, in which the leaves are fixed and the movement is of pulp and solutions. This filter is built after the Cassell design and was one of the first of the kind to be used. It shows its early construction, but is still doing efficient work. The leaves are made of canvas with a filling of cocoa matting, and are stitched with wire instead of the usual thread. This is said to prevent ripping and obviate a large portion of the usual repair bills. Solutions for precipitation are clarified by passing them through a filter press of the plate-and-frame type.

Precipitation on Zinc Shavings.—Precipitation is in the ordinary manner by the use of zinc shavings. There is little difficulty with the operation. The barren solution produced is used first on the concentration tables as wash. The precipitate is not melted or refined at the plant, it

having been proved more economical to ship it to smelters for final treatment. The precipitate is thoroughly dried, sampled and sealed up in cans for shipment. The fact that precipitate of this class can be shipped at a less cost than treating it on the ground is worthy of comment, for it is generally considered better practice to handle it at the plant, where there is less chance for loss due to differences of sampling, to say nothing of transportation charges. This matter ought to be investigated, particularly by plants situated conveniently to smelting installations, as I believe that generally no investigations are seriously made, it being taken for granted that treatment on the ground is cheaper.

Extraction and Consumption of Material.—The extraction totals 71.5% of the content, of which 43.65% is obtained by concentration and 27.85% by cyanidation. The consumption of chemicals is about 0.45 lb. of NaCN per ton, 0.3 lb. of zinc, 2 2 lb. lime and 0.4 lb. of the bromine salt. The mill consumes about 320 hp. and employs 35 men regularly in the operations. The costs are moderate for the method followed and are shown in the accompanying table.

DISCUSSION

The Shipment of Cyanide Precipitate.—In the JOURNAL of Feb. 8, 1913, Mr. Megraw comments on the shipment of cyanide precipitate to smelters as being cheaper than home treatment, and advises other plants to investigate the matter. However, he seems to state the vital objection to it in the same paragraph, "the chance of loss due to difference in sampling."

I have seen this thing tried out where I knew that every effort was being made to give the shipper a square deal, and as a check, the shipper's material was treated by itself, as far as producing bullion and byproducts went. The bullion alone carried more metal than the assays showed in the original precipitate, while there was a whole string of metalliferous byproducts still to be heard from.

Of course the balance might be in favor of the shipper, I remember hearing that one of the difficulties of the old Seattle Smelting & Refining Co. was due to erroneous sampling on exceedingly high-grade material, giving the shippers more than was coming to them, but usually the sampler will err, although perhaps unconsciously, on his own side.

Considering the expense of tight coopering or bagging, freight, the danger of theft in transit, and errors in sampling and assaying, it seems that a plant shipping cyanide precipitate, silver sulphides, or like material, is taking a long chance.

K. T. WHEELER.

In the JOURNAL of Feb. 8, 1913, Mr. Megraw, in his excellent article upon "Cyanidation at Cripple Creek," refers to the practice pursued at the Independence mill of shipping the precipitate to smelters, saying: "The fact that precipitate of this class can be shipped at a cost less than that for treating it upon the ground is worthy of comment, for it is generally considered better practice to handle it at the plant where the chance of loss, due to differences in sampling, is less, to say nothing of transportation charges. This matter ought to be investigated, particularly by plants situated conveniently by smelting installations, as I believe that generally no investigations are seriously made, it being taken for granted that treatment on the ground is cheaper."

In commenting upon this feature of Mr. Megraw's article, Mr. Wheeler, in the JOURNAL of Feb. 15, 1913, doubts the wisdom of this course for various reasons, although he gives no definite figures to support his opinion. Surely so experienced an operator as Mr. Argall is not shipping his precipitate, in preference to local reduction, without good reason. The fact that this plant is situated convenient to smelteries, and that gold precipitate is produced, may have its influence. In general, smelters do not buy this material upon the result of corrected assays, and, as it is a well known fact that the percentage of correction upon the assay of a product carrying largely gold is not so great as upon one in which silver predominates, it will be readily seen that the difference in favor of the smelter, arising from this cause, would not be so great as in the latter case.

The transportation problem is a serious one and, perhaps, is at its worst when long distances have to be covered by mule back or ox cart and steamer. I have seen various methods of packing tried, such as sacking in canvas and burlap, paper sacks inside of canvas protected by burlap, boxing, etc., but the only satisfactory method is to pack it in hermetically sealed tin cans protected by wooden cases. A satisfactory container for this purpose can be readily obtained at any cyanide plant by carefully opening and preserving the tin-lined wood cases in which the cyanide is received. These should be washed and dried. The precipitate is then placed in them, the tin cover soldered on, and the wood top securely fastened by nails or screws. A binding of light strap iron greatly strengthens the package and is desirable if it is to go any distance.

Cyanide operators would welcome comparative figures from Mr. Argall, showing the advantage of shipping precipitate instead of bullion. Various plants, with which I have been connected in the past, have shipped precipitate and then have later installed melting furnaces and shipped bullion. In every case it was felt that there was a distinct advantage, although no accurate comparisons were made, in favor of producing bullion, and in no case did any of these plants return to shipping precipitate after having once produced bullion.

A number of years ago I had an opportunity of making a thorough and fair comparison between the relative merits of shipping precipitate and the production and shipping of bullion, when Charles Butters requested me to go to Virginia City, Nev., and thoroughly investigate this feature of their practice. At this time the Virginia City plant was treating a considerable tonnage of Tonopah ore and old Comstock tailing. Both electrical and zinc precipitation were in use and the precipitate resulting from the two methods was quite different in character. The electrically precipitated material was high in lime and copper and also contained some lead. The zinc-box precipitate was similar to that produced in plants employing that method of precipitation when treating a silver-gold ore, except that it was not quite so high grade as that produced by present-day practice. The precipitate from the electric boxes formed the bulk of the product. Both classes of precipitate contained mercury and it was the practice to retort for its recovery until the Comstock tailing, which was its source, finally became exhausted, when retorting was discontinued.

From the beginning of operations at this plant it had been the practice to ship the precipitate, and this was continued long after the other Butters plants had found it to their advantage to ship bullion. It was generally supposed, owing to the refractory nature of the precipitate, and its low gold and silver content, that there was every advantage in favor of shipping precipitate rather than bullion.

I have no reason to doubt the accuracy of the sampling and assaying of the smelters to whom the precipitate was usually shipped, as their results generally agreed with the independent sampling and assaying at the mill; but, of course, it is to be understood that neither party made corrected assays. It will, therefore, be seen that the factor of dealing with an unscrupulous smelter does not necessarily enter into the case in hand.

For the purpose of experimentation there was erected, under my direction, a single stationary pot furnace and a small cupeling furnace. It was planned to carry on experiments to determine the relative advantages of fluxing and melting directly in graphite crucibles, producing a bullion containing most of the copper; and melting in the cupel furnace with litharge and other fluxes, running off the slag and cupeling the lead, thus producing a high-grade bullion. A number of experiments were carried out along both lines and it was finally decided that it would be more advantageous to adopt the method of melting in pots.

The results obtained with the cupel furnace all showed a substantial gain over shipping, but as the pot method was the one finally adopted it will suffice to give comparative figures for that method and shipping. For that purpose I will give the results of two experiments made upon two

samples taken from the precipitate comprising two separate and distinct shipments to the smelter.

These large samples were taken at the time that the precipitate was being sampled for assay prior to shipment. Every precaution was taken to have them truly representative of the mass of the material shipped, and in my opinion they were even more representative of the whole mass than the small samples taken independently at the mill and smelter for assay. Assays upon these independent samples generally checked closely.

In the first shipment the fine ounces of silver and gold realized by smelting 460 lb. of precipitate and marketing bullion were 2302.60 and 40.3595, respectively. The fine ounces in 460 lb. of precipitate, as shown by the assays at the smelter and mill, and upon which basis the lot of precipitate was sold, were 2250.01 of silver and 39.857 of gold. The gain in favor of shipping bullion was, silver, 52.59 fine ounces; gold, 0.5025 fine ounce.

COMPARATIVE COST OF SHIPPING 460 LB. OF PRECIPITATE AND
PRODUCING AND SHIPPING THE BULLION FROM 460 LB. OF
PRECIPITATE

Sampling and preparing for shipment	\$2 16
Drayage	0 55
Express	15 94
Sampling at smelter	1 15
Treatment charges	22 55
Deductions, gold	16 64
Deductions, silver	25 86
Total cost of shipping 460 lb. precipitate	\$84 85
Cost of melting at \$0.01 ¹ per oz. doré bullion	\$32 55
Canvas on bars, etc	0 30
Drayage	0 48
Express	11 86
Refining charges	33 38
Total cost of melting 460 lb. precipitate and shipping as bullion.	\$78 57

Net amount realized shipping bullion was \$2074.04, and that realized shipping precipitate was \$2026.88, a difference in favor of shipping bullion of \$47.16.

This would amount to a saving of \$0.02079 per fine oz. of doré bullion (fine ounces gold plus fine ounces silver).

In the second shipment the fine ounces of silver and gold realized by melting 300 lb. of precipitate and marketing bullion were 1297.71 oz. silver, and 21.532 oz. gold respectively. The fine ounces in 300 lb. of

¹ This figure includes the cost of treatment at the smelter.

precipitate, as shown by the assays at the smelter and mill, and upon which basis the lot of precipitate was sold, were of silver, 1236.94 and of gold, 21.61. The gain in favor of shipping bullion was 33.77 oz. of silver and 0.078 oz. of gold.

COMPARATIVE COST OF SHIPPING 300 LB. OF PRECIPITATE AND
PRODUCING AND SHIPPING THE BULLION FROM 300 LB. OF
PRECIPITATE

Sampling and preparing for shipment.....	\$1.41
Drayage.....	0.36
Express.....	11.14
Sampling at smelter.....	0.80
Treatment charges.....	12.83
Deductions, gold.....	9.08
Deductions, silver.....	14.66

Total cost of shipping 300 lb. precipitate..... \$50.28

Cost of melting at \$0.01 per oz. doré bullion.....	\$12.11
Canvas on bars, etc.....	0.10
Drayage.....	0.17
Express.....	5.19
Refining charges.....	12.51

Total cost of melting 300 lb. precipitate and shipping
as bullion..... \$30.08

The net amount realized when shipping bullion was \$1167.66, and the net amount realized when shipping precipitate was \$1129.49, a difference in favor of shipping bullion of \$38.17. This would amount to a saving of \$0.02969 per fine oz. of doré bullion.

The saving for four consecutive months, when the shipments of doré bullion amounted to over 50,000 oz. per month, was in July, \$1090.52; August, \$1056.21; September, \$1178.67; October, \$1003.61; a total of \$4329 saving for the four months.

Although the cost of melting (1c. per ounce) was unusually high at this plant, due to the refractory nature of the precipitate, the saving in favor of local melting and the shipping of bullion is apparent. I have obtained costs of melting as low as 0.1c. per ounce in Central America, and others have done much better than this where a large volume of high-grade silver precipitate was melted under the most favorable conditions.

Within certain limits the treatment charge upon bullion is usually based upon a flat rate per gross ounce, so that while apparently the rate is no higher upon bullion containing considerable base material, as a

matter of fact as the amount of base material increases, the rate per fine ounce of doré also increases in direct proportion to the increase of base. To illustrate how this might affect the saving due to melting, I have calculated the saving which would have resulted if bullion 950 fine had been shipped instead of the base copper bullion from the plant in question. During the four months mentioned, the saving in July would have been \$1557.36, that in August \$1508.40, in September \$1683.24, and in October \$1433.25. It will, therefore, be seen that where a high-grade precipitate is produced which can be converted into comparatively high-grade bullion at a low cost, the saving by local melting in a large plant is greater than that indicated by the figures which I have given.

The saving indicated in this case is plainly due to two causes: First, that the ordinary cyanide plant can actually convert silver-gold precipitate into bullion cheaper than the charge made by the smelters for this service; second, that with local melting and the proper treatment of the byproducts, more bullion is realized than that indicated by the ordinary uncorrected assays.

It is only fair to say that these comparisons were made a number of years ago and that the rates of treatment for precipitate and bullion taken are those obtaining at that time.

G. H. CLEVELAND.

Palo Alto, Calif., Mar. 16, 1913.

In the discussion regarding the shipment of cyanide precipitate, I would like to direct attention to one reason which may account, in some cases, for low results when shipping bars. This is the shipment of imperfectly refined bars, which yield such erratic assay results that the purchaser must necessarily put a low valuation on them for his own protection. In the annual report of the British Mint for 1896, Roberts-Austen describes a cyanide bar weighing 393 oz., which was paid for at £965. This bar was refined by itself and yielded gold worth £1028. The shipper of the bar lost £63 or over \$300. After paying for the refining, such a loss might easily be fatal to shipment of bars as against precipitate in a comparison of costs.

In the JOURNAL for Apr. 13, 1912, I have given a table of erratic assays of cyanide bars from the Mercur mine. It would be a hazardous undertaking to determine from these assays just how much gold these bars contained. Some bullion deposited by the Mercur mine just before closing down was better refined and higher grade. Samples from three bars of these later shipments were assayed in duplicate in three laboratories with the following results:

	1st Bar gold	2d Bar gold	3d Bar gold
1st Laboratory.....	920.1 fine	916.3 fine	884.2 fine
	.2 fine	.7 fine	.5 fine
2d Laboratory.....	920.8 fine	916.8 fine	884.5 fine
	.8 fine	.5 fine	885. fine
3d Laboratory.....	920.1 fine	916.5 fine	884.0 fine
	.3 fine	.6 fine	.3 fine

These results show a vast improvement over the former assays of Mercur bars.

FREDERIC P. DEWEY,
Assayer, Mint Bureau.

Washington, D. C., Apr. 28, 1913.

CHAPTER IX

CONTINUOUS DECONTAMINATION OF SLIME

The advent of a new process is not regarded with excitement in the metallurgical world. Too many of them have appeared, led a struggling existence for a few months, or longer in some cases, and then disappeared without leaving many ripples in the places where they existed. Development of existing and proved processes, however, is regarded with interest, and as each step in advance proves its worth it is incorporated into the system of approved and satisfactory methods.

In the days when the decantation method of treating slime was the only one known, operators made serious efforts to improve it, particularly



OPHIR MILL, OPHIR, COLO.

to find some way of avoiding the losses which occurred in discharging residues containing moisture charged with both cyanide and valuable metal in dissolved form. The necessity for improvement brought forth the slime filters, and for a long time experiments in decantation were discontinued. After many years of filtering, however, the suspicion remains that the decantation process might be improved so as to compete with filtration, the cost of operation and maintenance of existing filtering apparatus going far toward strengthening that suspicion. It may be said

that the cost of slime filtration varies from 10c. to maximum figures which would be regarded with suspicion were I to mention them. Including cost of operation, maintenance and loss in dissolved metal, the minimum figure above mentioned is extremely low and I doubt whether there are any number of plants in existence attaining it. It will be seen that there is, then, an opportunity for improvement, for if any procedure can successfully reduce these costs or losses, or even equal them without the use of complicated and expensive machinery, it will stand a good chance for approval and success.

Development of Proposed System.—Lately some progress has been made toward developing a process of continuous decantation, which is nothing new, but a development of the methods used before the filters came into use. In the old intermittent decantation process the slime after being agitated with a quantity of solution was allowed to settle, the solution decanted off and a new bath of solution put on. This was in turn agitated, allowed to settle and again decanted, the process being carried on as many times as was thought necessary. The efficiency of fresh solution washes was recognized, particularly when this solution was barren or freshly made up or regenerated, but the difficulty with this system was the enormous quantities of solution to be handled in addition to the impossibility of reducing the moisture content of the final pulp to such a point that too much dissolved metal and valuable cyanide should not be thrown away. This new development attempts to accomplish a solution of both difficulties by means of a continuous-decantation and thickening process using solutions flowing opposite to the course of the pulp. The fact that this method has seemed feasible to a number of competent metallurgists and is actually in operation in a number of instances makes it worthy of attention and in this paper two such plants will be described.

Milling in Cyanide Solution.—The plants in question are the mills of the Ophir Gold Mines, Milling & Power Co., at Ophir, San Miguel County, Colorado, and of the Blue Flag Gold Mining Co., in the Cripple Creek district. Both are of recent construction, and while operations have not been carried on long enough to provide satisfactory details of cost and maintenance, the metallurgy has shown sufficient promise of success to warrant consideration.

The Ophir mill crushes ore with stamps, the installation including 20 of 850 lb. each with 6-in. drop and 104 drops per min. From the stamps the pulp goes to a Dorr classifier, where the slime is passed to a Dorr Thickener and the sand reground in a Hardinge mill, from which it is pumped back to the classifier, the circuit being closed and only solids of sufficient fineness reaching the thickener.

A point of interest is that the overflow solution from the first thickener

The overflow solution from the first of these thickeners is returned to the mill solution tank, where it is used in milling and classifying, the result being a concentrated solution for precipitation. The barren solution from precipitation goes to dilute the inflow into the second thickener, the overflow from which goes back into the first. The accompanying flow sheet shows the movement of pulp and solution throughout the mill. It will be noted that water is taken into circulation at the end of the washing period, the logical point of entry for it, and practically replaces the solution which comes with the solids to that point.

Progress of Solutions.—It will also be noticed that the progress of solutions is contrary to the direction of pulp flow, the solutions being constantly enriched. The figures given in the flow sheet are based on ore carrying \$5 in gold and the contents of solutions are given in pounds of KCN and lime. The calculations of thickening are based on withdrawing a pulp from each thickener which consists of half solids and half solution. This is accomplished in practice, in fact a slightly thicker pulp can be obtained, thus increasing the efficiency of the process. It has been in operation only a short time but the results obtained have been in complete accordance with the figures shown. It will be seen that the installation is simple and inexpensive, may be operated by a minimum amount of labor and accomplishes a washing of pulp and removal of dissolved metals that is, to say the least, comparable with good filtration work.

The lime in this mill is added at the bins and goes through the circulation with the pulp. The consumption amounts to about 0.9 lb. per ton of ore. The value of the process depends a great deal on using solutions of low cyanide content and the existence of a plentiful water supply, which conditions are satisfactorily met in this case. The flow sheet shows all the details of the process and apparatus and no further explanation is needed.

The Cripple Creek Installation.—The Blue Flag mill is situated between Cripple Creek and Victor in Colorado. The ore averages between \$5 and \$6 and is to a great extent from the dumps. The coarse ore is dumped on to a steel conveying and picking belt where a portion of the barren rock is removed. From the picking belt it is passed through a 12×18-in. Dodge crusher and through a Symons disk crusher from which it emerges reduced to about $\frac{3}{4}$ -in. cubes. The finely crushed ore is then delivered to a special form of chilean mill which consists of a concave die ring 7 ft. in diameter, over which convex rollers pass. The rollers are small, weighing only 700 to 800 lb. each. The mill makes 36 r.p.m. and grinds the ore, in cyanide solution of $1\frac{1}{2}$ per ton strength, through a 30-mesh screen. Solution used at the rate of about five to one.

The pulp as it comes from the mills is delivered to the series of agitating tanks through which it passes continuously. These tanks are 14

ft. diameter and 16 ft. deep having cone bottoms at an angle of 55°. The agitation is pneumatic, elevating the pulp through a central tube.

This point in the process is open to criticism, as the pulp from the mills is in too coarse condition for economical agitation, to say nothing of the metallurgy of it. If it is true that finer crushing is not necessary, then it would seem reasonable to separate the coarse portion of the solids and treat it separately by some more economical means. The pulp undergoing agitation has the following approximate grading analysis: On 30 mesh, 0 to 0.5%; on 40 mesh, 4 to 9%; on 60 mesh, 22 to 24%; on 80 mesh, 35 to 36%; on 120 mesh, 58 to 60% and through 120 mesh, 40 to 42%. The grading statement is cumulative. Pulp of this class requires excessive power to keep it in circulation.

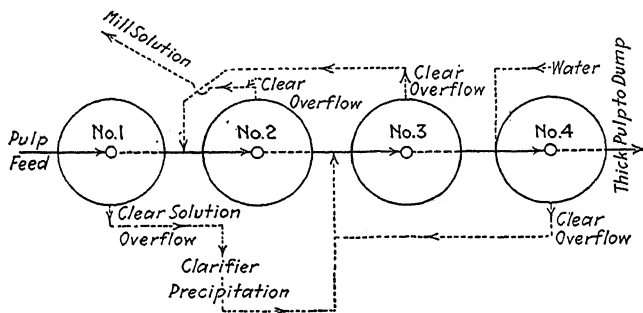


DIAGRAM OF CONTINUOUS COUNTER-CURRENT DECANTATION AT BLUE FLAG MILL.

Continuous Washing.—The pulp is in circulation through the agitation tanks for about nine hours and the extraction in them amounts to about 70%. In considering the extraction results it must be remembered that this is on the refractory ore of the Cripple Creek district. The cyanide consumed in the process is about 0.35 lb. of which 0.15 lb. is mechanical loss. Lime is added to the ore bins and progresses with the pulp, the consumption being about 2½ lb. per ton milled.

The pulp from the agitators is taken to a series of four thickeners and is washed through them after the manner described in the Ophir mill. The accompanying diagram shows the flow of pulp and solutions through them. In the case of the Blue Flag mill, also, it has been found possible to secure a thickened pulp containing less than 50% moisture. In this instance, also, it has been found that the calculations, based on 50% thickening, are borne out in practice.

Other Combinations.—It should be remembered that this development is not recommended to cure all the ills that cyaniders are heir to, but is a progression along conservative lines and one that should eventually lead to a fixed system available in cases where the character of the ore

will bear such treatment and where other local conditions are favorable. It is a system which, while not yet perfected, will be well worth following. It is easy to see that other combinations are possible, such as using a greater number of thickeners, of this type or any other satisfactory one, and by precipitating two or more different solutions. The two installations mentioned are not by any means the only ones using it. They may not even be the ones where it is most advanced, the idea in presenting the matter being principally to draw attention to the fact that there is a system in course of development which may possibly lead to decided economies in the cases of ores to which it is applicable.

CHAPTER X

PRACTICE AT TONOPAH

The Tonopah district offers to the student of contemporary metallurgy what is probably the most interesting demonstration of the efficiency of the cyanide process applied to silver ores. This is not to say that the general methods in use are original, as they are not, but the application of these methods has been attuned to the requirements of the particular ores to be treated and the problems have been attacked and solved with praise worthy conservative judgment. It is both interesting and noteworthy that in all the Tonopah district there is not one idle reduction plant, nor one which has been designed by a tyro to include exaggerated ideas or "freaks." All the plants conform to standard practice, are built after tried and proved plans and embody only such variations as have seemed best adapted to care for the characteristics of the local ores.

It is also noteworthy that there is not a mill in Tonopah which has not paid for itself out of profits won from the ores of the mine it was designed to treat, the only exception at the present time being one, or possibly two, of the most recently built mills which have not yet had time to accomplish this feat, but which will, without any question, complete the requirements within a few months. Possibly the most noteworthy accomplishment of this kind is that of the West End mill, which returned sufficient profit within seven months to pay for the installation. It is to be remembered that this is an old mill, rebuilt twice before reaching its present condition, but still performing admirable work at a cost which is comparable with that attained by the more recent plants.

The Ores of Tonopah. The geology and character of the Tonopah ores have been sufficiently described in the technical press from time to time and it will be sufficient to consider them here only in relation to their attitude toward cyanidation. They may be said to be of medium hardness and crush without any great amount of trouble. This statement is made not so much in considering the ores as a single problem, but as comparing them with the rock treated in the cyanide plants of other districts. For instance, it might be said that the Tonopah ores are somewhat harder than that of the Porcupine district, which differ essentially, of course, in character, and not so hard as many of those of the Cobalt district. They are perhaps about equal to most of the ores of the Pozos dis-

districts of Mexico. They may, briefly, be said to be medium ores as far as resistance to fine reduction is concerned.

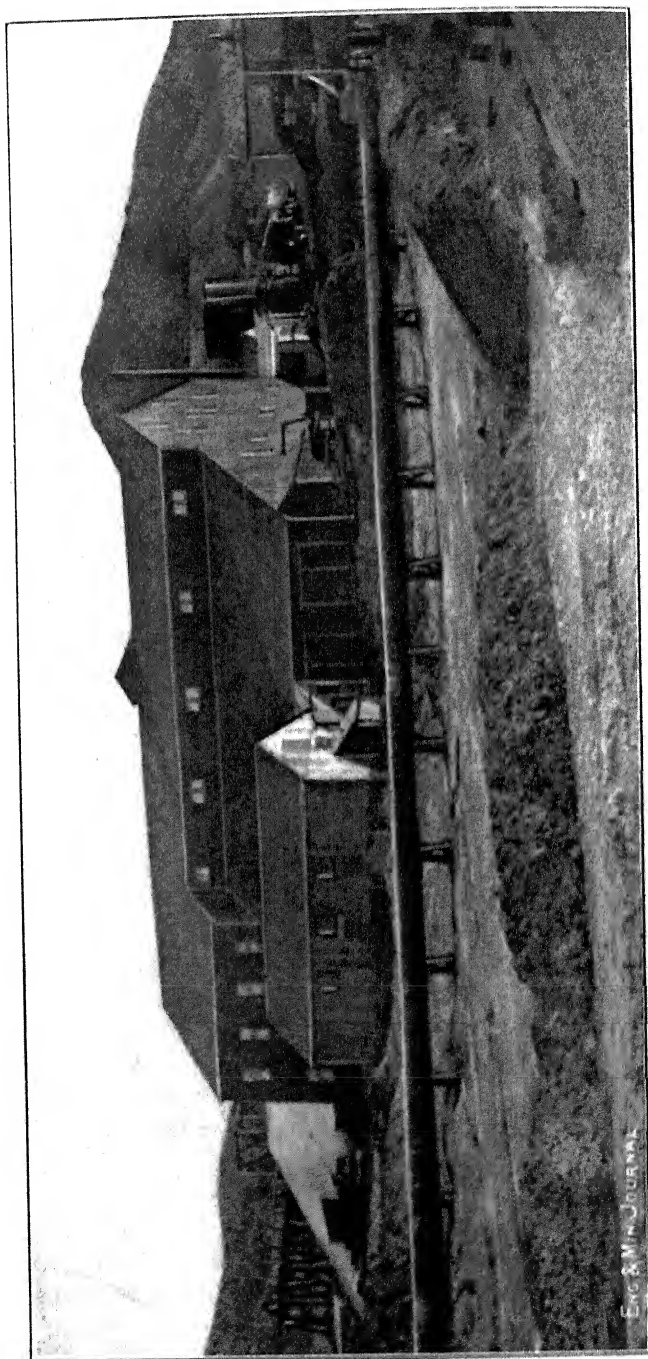
There are under treatment, as is usual in districts as comparatively recent as Tonopah, both oxidized and sulphide ores. The oxidized ores have not presented any great difficulties of metallurgy, but the sulphides have, in many cases, presented a complexity of nature which is not so simply handled. Reference to the current descriptions of these ores will show their character, but it is probably not superfluous to call attention to the fact that in some of the high-grade sulphide ores mercury has been found in small quantities. I have seen a specimen of sulphide ore which shows a quantity of cinnabar. These sulphides are not always simply treated and in some cases, as will be noted, it was found advisable to remove them by concentration before proceeding to the cyanidation of the bulk of the ore.

The mill of the West End Consolidated Mining Co. is situated at the southeast edge of the town of Tonopah. At the mine shaft the ore is crushed to break up all large boulders. The ore is brought to the mill in auto trucks and delivered into a bin, from which it passes through a 10×20-in. Blake crusher. A bucket elevator delivers the crushed ore into a 32×72-in. trommel with 1-in. apertures, the oversize going to a No. 3 Kennedy crusher. The crusher product joins the undersize from the trommel and is carried by a belt conveyor with 14° incline, 14-in. belt, to the 200-ton battery bin.

Stamp Installation.—There are 10 stamps of 1200 lb. and 10 of 1300 lb., fed by means of suspended Challenge feeders. The stamps drop through 6½ in. 101 times per minute. The stamp duty at present is about 7.5 tons per day per stamp.

From the stamps the pulp is fed into two Dorr classifiers, which deliver into two 5×18-ft. tube mills. The classifiers are placed close in front of the batteries, and the tube mills are ranged with their long axes parallel to the batteries, the discharge end of one of them fronting the feed end of the other. This has been done with the idea of occupying the least possible space in the direction of the mill fall. As the mill is a reconstructed one, having formerly been the first amalgamating mill in the district, a free hand in designing the arrangement was not obtainable, but the advantages have been well handled and the arrangement is such as to permit economical handling of the material.

Tube-Mill Linings.—It will be noticed that the tube mills in use are of large diameter and short length. It seems that this type is meeting with almost universal approval from metallurgists of the present day, the conclusion being that in the former long mills there was a great deal of space at the discharge end which did not perform any useful work. The change toward larger diameters and less length has resulted in an increased pro-



WEST END CONSOLIDATED MILL, TONOPAH, NEV.

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duction of slime at a power consumption, per ton of ore, equal to or less than with the long tubes. There is an added advantage in the smaller floor space occupied.

At the West End mill the linings used in the tube mills are of the smooth, cast-iron type, as hard as they can be made. The operators claim that with this lining the power consumption is less than when silex is used or any of the ribbed types and that the output is satisfactory in quantity and character. In this point the investigator has to face a peculiar problem which seems to have no direct solution. Smooth linings for tube mills were used in the days long ago and were discarded in most places for silex or the ribbed types, where the wear does not come directly upon the lining, or at any rate, is not supposed to do so. Yet we have here a recurrence to the older type, with the claim of better results. This circumstance would not be so strange if the operators in the district working upon the same character of ore were in accord, but they are not. The Belmont mill has made tests using silex in competition with smooth linings and giving preference to the silex. Tests have also been made at the West End mill, and the result is said to be in favor of the smooth lining.

In cases of this kind no definite conclusions can be drawn at the present time, the only recourse being to await developments, it being more than probable than the operators in the district will eventually agree upon the most effective form. It is noteworthy that both the smooth cast-iron linings and the silex linings were tried out in Mexico years ago and discarded in favor of ribbed linings. The Komata form was tested here, but the increased power required, together with its high cost, have prevented its use. At the Goldfield Consolidated mill, however, these linings are in use and it is stated that they are the most economical and effective ever tried. It is true that there is an increase in the power required to drive the mill, but the increased production more than compensates for the additional power used.

When the West End plant was first started both of the tube mills were moved by a 100-hp. motor and the pebble charge was carried at or slightly below the center of the mill. The power was ample with this arrangement. With the desire to increase capacity, experiments were made with the object of securing greater capacity by increasing the charge of pebbles in the tube mills. It was soon found that the power was insufficient, but as a result of many tests; the 100-hp. motor formerly driving the two mills was replaced by a 150-hp. motor and the pebble charge carried six inches above the mill center.

Solely by this change the capacity of the plant was increased from 100 to 150 tons per day, the increased work performed by the tube mills allowing a coarser screen to be used on the batteries. The actual power

taken by the two mills is from 120 to 125 hp. This result is noteworthy, and has the effect of rendering the use of the counter-spiral discharge unsuitable for a mill of the kind, as the high pebble charge is likely to force out some of the pebbles through the discharge end. A grating is usually used in mills of the kind, which, of course, precludes the feeding of pebbles at the discharge end. Experiments with tube mills of large diameter and varying pebble charges ought to be productive of interesting results.

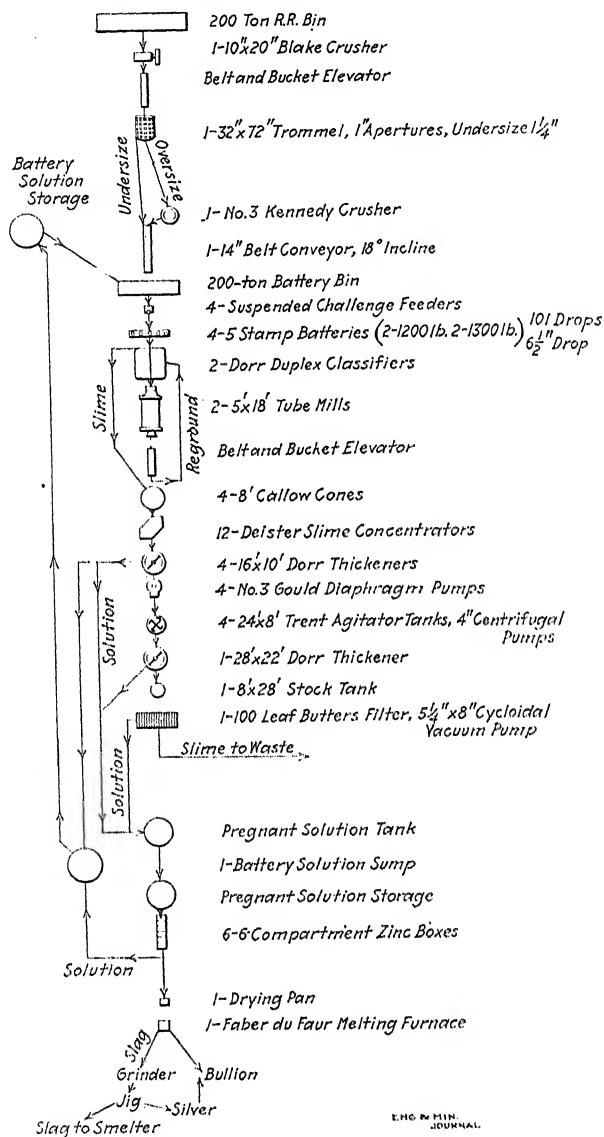
Concentrating the Slime.—The tube-mill product is returned to the classifiers by means of a bucket elevator and the slime from the classifiers is taken to the concentrating department of the mill which is of recent installation. The slime is led to four 8-ft. Callow thickening cones, the thickened slime being concentrated on 12 Deister slime concentrators. After concentration the slime tailing from the concentrators is returned to four Dorr thickeners, 16×10 ft. each, part of the overflow being used for the concentrator-table washes and returning with the pulp to the thickeners. The slime pulp contains about 90% through a 200-mesh screen.

Four diaphragm pumps are used for lifting the thickened slime from the thickeners into the agitation tanks. The suction of these pumps is connected directly to the outlet from the thickeners and consequently any regulation of thickener discharge has to be made by varying the adjustment of the pumps. Personal experience has not been such as to inspire a great deal of confidence in diaphragm pumps, as they have usually proved unreliable and likely to lose their priming or break the diaphragms at most inopportune times, but at the West End mill they are working successfully and have given entire satisfaction. Due to the fact that they are essentially a suction pump, they have been placed at a height where their delivery can flow by gravity into the agitation tanks.

The system of having the pump suction connected directly to the thickener has the advantage of avoiding spilling of the pulp and makes a direct and tight connection from the thickeners to the agitation tanks, but the disadvantage is that adjustment or change of the thickener discharge has to be made on the pumps, either by changing the throw or speed, making the operation slow and necessarily performed at a distance from the thickener itself. It seems possible that a preferable arrangement would be to allow the thickened slime to fall directly into an appropriate sump from which it could be picked up and delivered to the elevation required. This change would allow of prompt and effective regulation of the thickener outflow.

Agitation System.—There are four agitation tanks, each 24×8 ft., arranged for continuous agitation and carrying Trent agitators. The continuous arrangement is such that in the passage from tank to tank the pulp is required to pass through the pump suction and enter each tank through the Trent agitators, thus insuring the maximum agitation and

avoiding short circuits across the top of the tank. The centrifugal pumps used are the Kelly & Campbell, a local make which has been designed to make replacement of worn parts easy and rapid, and the wearing part or



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FLOW SHEET OF WEST END MILL.

liner is designed to require no machining so that it can be chilled all over. These pumps are used throughout the mill and, in fact, throughout the district, and have given entire satisfaction.

The difficulties encountered with Trent agitators at other mills, notably the Hollinger, at Porcupine, Canada, and at the Mexican, in Virginia City, Nev., are not found at the West End mill, nor in some other mills in the district where they are largely used, as will be noted. Here they give satisfactory results and the operators are well pleased with their performance. The centrifugal pumps used have 4-in. delivery and give a pressure of from 14 to 16 lb. per sq. in. The agitator arms make $3\frac{1}{2}$ r.p.m. and the operation of the agitator is said to require from 7 to 9 hp., varying, naturally, with the consistency of the pulp and somewhat on other temporary variations.

From the agitation tanks the pulp is elevated by means of a 6-in. centrifugal pump of the type already mentioned into a 28×22-ft. Dorr thickener, the overflow solution going to the pregnant-solution tank and the thickened slime into an 8×28-ft. stock tank, which feeds the filter.

The filter is a 100-leaf installation of the usual stationary vacuum type and presents no novelties in the system of operation. The slime is of such character that a light, soft, spongy cake can be made which is easy to wash, a cake $1\frac{1}{2}$ in. thick being readily made and washed. As proof of the ready washing character of the material the operators have shown that shortly after one replacement of the contained solution is made, the value of the effluent solution drops down nearly to the value of the wash solution used. By a "replacement" is meant the passing through the cake of a quantity of solution equal to the amount contained as moisture in the cake. By passing another replacement of water through the cake the cyanide-bearing solution is nearly entirely displaced, the water taking its place. It should be remembered, however, that a cake of this homogeneity and porosity is unusual and it would be difficult to point to many examples of the kind. A $1\frac{1}{2}$ -in. cake is made in from 45 to 60 minutes and is given a three-hour solution wash in order to take advantage of the additional extraction noted below. Due to the local conditions, the residue from the filtering operation has to be repulped with a minimum of water and pumped away, there being no available method of running to waste by gravity.

Rotary Vacuum Pump.—The vacuum pump is a type I have not seen used for this purpose, and as it has advantages which are material, it is well worth mention. It is a Connersville cycloidal machine, $5\frac{1}{4}$ ×8 in., and has $2\frac{1}{2}$ -in. suction and discharge. It consumes only three to four horsepower and maintains a vacuum of 19 in. at this altitude (6000 ft.) The machine is low in first cost, occupies an exceedingly small floor space and has an admirable maintenance cost, there having been no repairs on it since its installation. Machines of this class ought to be investigated for this work, as the record of this particular installation is admirable

in the extreme. It is constructed like a positive blower, having two lobes revolving in conjunction with each other.

The filter tank is equipped with air lifts to aid in keeping the material in suspension. After forming the cake on the filter it is given a solution wash for three hours, during which time an additional extraction of silver of from 1 to 2% is gained. The point of additional extraction is extremely interesting and is one which has been verified in several of the mills in the district, the additional metal dissolved varying from 1 to 3% in various plants.

Of the filter leaves, five are acid-treated each day, using HCl of 0.5 to 1% strength. It has been shown in many mills of late that the frequent treatment of filter leaves in dilute acid lengthens their life considerably and does not tend to harden the canvas as does more concentrated acid.

Zinc shavings are used in the usual way for precipitating the metal from solutions, the installation consisting of six boxes of six compartments each. The precipitate is collected, partially dried and melted in Faber du Faur furnaces, which are equipped with a special low-pressure burner.

The ore treated varies in value from \$18 to \$20 per ton, the proportion of silver to gold being about as 100:1. The extraction in the mill varies from 90 to 92% of the contained metal. The power consumed is two horsepower per ton of ore treated, and the regular force of operatives consists of 18 men.

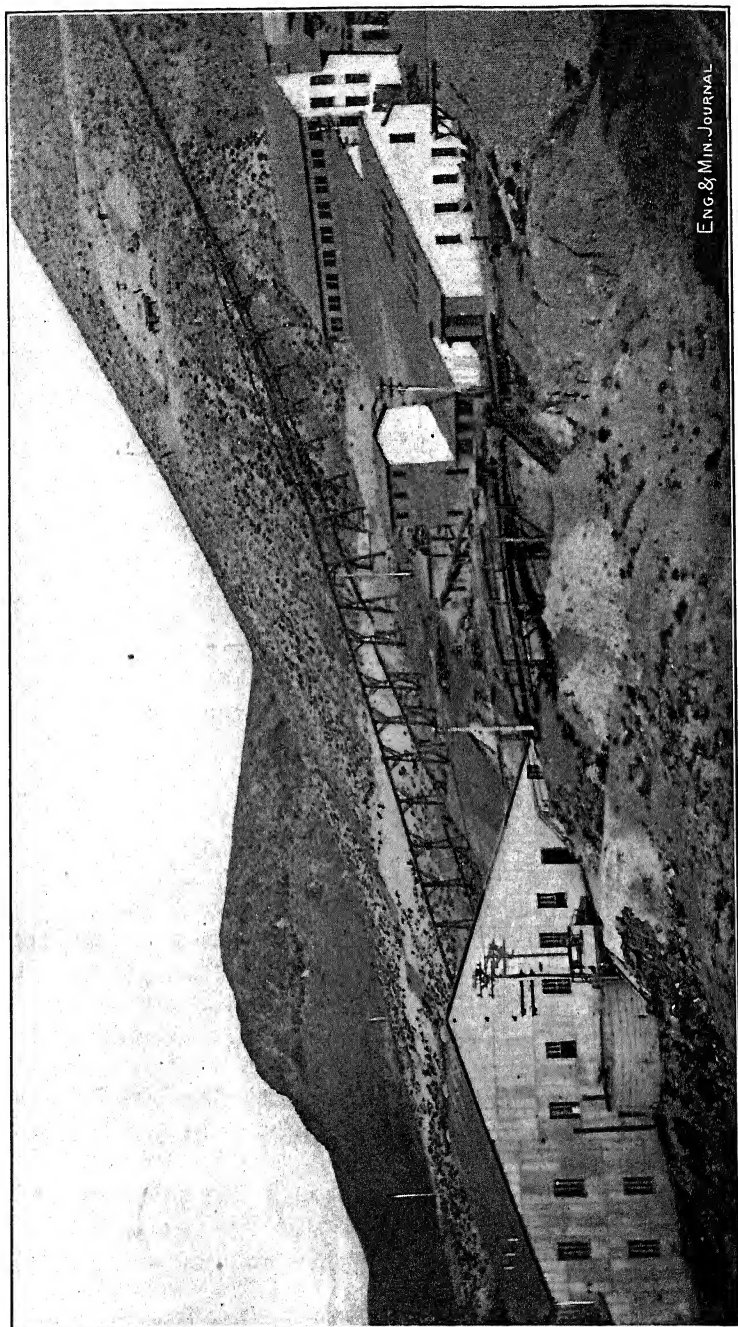
The consumption of the principal supplies used in cyaniding is as follows: KCN, 3 lb. per ton of ore treated; CaO, 3 lb.; lead acetate, 0.5 lb; zinc, 1.8 lb.; pebbles, 6 lb. The total cost of treatment amounts to about \$3.30 per ton of ore treated. The accompanying flow sheet gives the details of the mill operation and the machinery used.

The Montana-Tonopah Mill.—The Montana-Tonopah mill is one of the original mills in the district to treat ores by total sliming. It was constructed to make use of concentration, but this has been partially eliminated and now is using only a partial concentration system.

The ore is first put through a No. 5K Gates gyratory crusher, from which it is elevated and passed through two No. 3D short-head crushers of the same make, thence going by means of a 14-in. belt elevator into the battery bin.

There are 40 stamps of 1100 lb., dropping 102 times per minute through 7½ in. The screen used is a "ton-cap" equal to about 25 mesh. Stamp crushing is universal in the camp and the Montana-Tonopah is in line with general practice.

From the batteries the pulp is classified in cone classifiers, the slime going to the settlers and the sand being concentrated on eight Wilfley



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MILL AND CYANIDE PLANT OF MONTANA-TONOPAH CO., TONOPAH, NEV.

sand tables. The sand from the concentrators passes to two Dorr duplex classifiers operating in closed circuit with two Allis-Chalmers tube mills, each 5×22 ft. The grinding capacity of this mill is in excess of its leaching and agitating capacity and only one of the tube-mill sets is in use, the other being held in reserve so that no time is lost on account of relining or repairing the tube mill.

It will be noticed that the tube mills in this installation are the long type, which is due to the fact that they were installed before the general opinion turned toward the short, large-diameter mills. Most of the tube mills used at present in the district are the latter type, which is most generally favored. Smooth cast-steel linings are used in the tube mills, this arrangement having proved satisfactory in efficiency and economy.

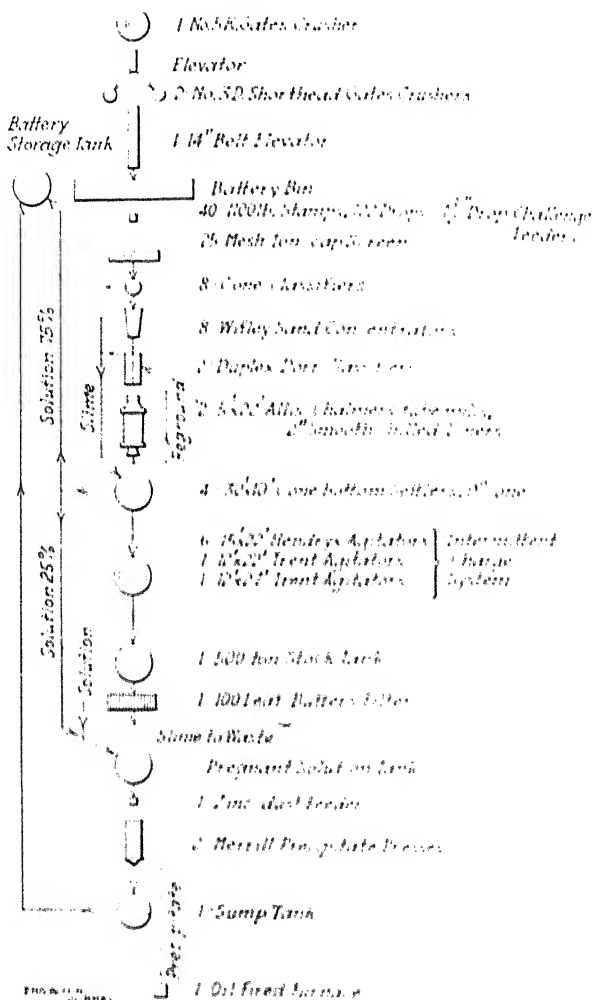
Types of Agitators in Use.—The slime is settled in cone-bottom tanks, of which there are four, each 30×10 ft., with a 9° pointed bottom. The thickened slime is taken to one of eight agitation tanks, which are operated on the intermittent-charge system. There are six 22×15 -ft. tanks, containing Hendryx agitators; one 22×12 -ft. tank, and one 27×12 -ft. tank, each equipped with a Trent agitator.

In this plant an opportunity has been had to compare the work and results accomplished with the Trent and Hendryx systems, and it is noteworthy that the operators prefer the Hendryx, although admitting that it requires a greater amount of power to drive it, resulting in a greater expense. It is claimed that the extraction results are better with the Hendryx device and that it gives a great deal less trouble than the Trent. The main difficulty with the latter seems to be that it is extremely likely to become stopped up with splinters or caked slime and also that it is not so efficient in getting extraction results. This matter of difference of opinion in reference to agitators will be mentioned again in discussing further the practice in this district.

The agitation in these tanks is continued for 54 hr. in a solution containing 5 lb. KCN per ton. Lime is added to the agitators in powdered form, the consumption being three pounds per ton of ore. The treatment solutions are kept heated to 110° , by which means the extraction of silver is said to be materially increased.

Stationary Vacuum Filter.—The filter installation consists of a stationary plant of the Butters type, containing a total of 140 leaves, of which only 100 are required to handle the capacity of the mill. The filter is worked in five cycles per 24 hr., three hours being used for taking out and acid-treating the leaves, the filtering operation ceasing for that period. Each day six leaves are treated, and weak acid is used for the process, the average being about 2% HCl. Frequent treatment with weak acid keeps the filter leaves in good condition, avoids accumulation of large quantities of lime on the canvas and notably lengthens the life of the leaf. The weak

acid does not destroy the thread used in sewing the leaf and does not harden the canvas as strong acid does. In treating the leaves frequently, only a small quantity of lime is allowed to accumulate on the leaves and the weak acid is effective in removing it.



FLOW SHEET OF MONTANA-TONOPAH MILL.

The time of forming the cake is 45 min., a 1½-in. cake being built up in this time. Solution wash is continued for three hours and a slight additional extraction is gained in this time. The additional extraction gained on the filter is so small in this case as to be almost negligible, thus differing from the experience of some plants in the district, where appreciable quantities of metal are dissolved during the solution-washing period.

Due to the fact that a railroad spur runs through the property, it was necessary to design the mill in two units, one of which includes the crushing, grinding and concentrating units and the other the cyanide plant. This disadvantage is somewhat offset by the advantage gained in receiving supplies directly at the mill and the loading of concentrate without haulage expense. The concentrate is shipped to a smelting plant.

Zinc-dust Precipitation.—The Merrill system of zinc-dust precipitation is used, the consumption of zinc being equal weight with the bullion recovered. The precipitate is melted in oil-fired furnaces, no acid treatment being practised.

The total extraction resulting from the ore treatment is about 92.6% and this total is divided into 20% in concentration, 20% in contact with solutions and 52.6% in agitation. The cost of beneficiation is placed at \$3.09, which figure does not include the general expense items. The consumption of material is 8 lb. lime per ton of ore treated, 3 lb. cyanide, 0.75 lb. lead acetate; pebbles, 1½ lb. per ton treated. The mill treats from 145 to 150 tons per day, and the ore contains 20 oz. silver and about \$4 gold. The mill requires 320 hp. for its operation and employs 19 men regularly.

As this is the oldest mill in the district maintaining its original construction and treatment plan, some of the later ideas are not included. This is to be especially noted in the case of the tube mills, the long type being used instead of the shorter ones, which conform to later ideas.

CHAPTER XI

PRACTICE AT TONOPAH Continued

The mill of the Tonopah Extension Mining Co. is situated at the edge of the town of Tonopah. It is one of the later mills and embodies more recent ideas in metallurgy of the Tonopah ores. Some of these departures are of much interest, among them the use of tube mills in tandem.

The ore is first crushed through a No. 4 Kennedy gyratory crusher and is then taken by an inclined belt conveyor to the mill bins. From these it is fed through suspended Challenge feeders into the stamps. There are thirty 1050-lb. stamps having 7-in. drop and 100 drops per min. Four of the batteries are equipped with 12-mesh screens and two with 3-mesh screens of the "ton-cap" type, the object of the use of these different screens being to furnish a pulp of varied coarseness with the idea of increasing the efficiency of the tube mills. It is maintained that the coarser portion of the pulp not only provides a means of satisfactorily using a part of the grinding action of the pebbles which is expended in crushing upon themselves, but actually assists in grinding the finer portions into slime.

Tube-mill Arrangement. From the batteries the pulp is received by a duplex Dorr classifier, which removes the slime and delivers the sand and coarser rock into the first tube mill. This is a machine 5 ft. diameter and 18 ft. long, following the recent accepted design. It is equipped with spiral scoop feeder and Komata lining, and makes 27 r.p.m. In this mill there is but one passage of the pulp, there being no return of oversize to it. It performs a heavy duty in reducing the larger particles of the pulp, as the analysis shows.

From this first tube mill the pulp is received by a second Dorr classifier, the slime is taken out and joins the stream from the first, and the sand requiring regrinding is led into the second tube mill. This mill is the same size as the first one, but is equipped with a smooth cast lining, in distinction to the first which has a Komata lining. Here the fine sand is ground into the slime required for total pulp. The product issuing from the mill is returned to the second classifier, thus forming a closed circuit from which only the portion light enough to pass over the discharge of the Dorr classifier issues. The accompanying table shows the classification of the entering and issuing pulp of each mill and also the classifier overflows.



TONOPAH EXTENSION MILL.

The Agitation System. From the regrinding system the pulp is taken to four cone-bottom settling tanks, each 24×16 ft., where the collection of slime is made, the overflowing solution being either pumped back for further use or sent to the precipitation department, according to conditions. This bulk of solution is used to maintain the balance between precipitation and the total solution used in the mill.

From the settlers the slime is drawn off into the agitation tanks, of which there are four, each 24×16 ft., all equipped with Trent agitators. At the Extension mill the Trent agitators are regarded as highly efficient and satisfactory devices, although it is acknowledged that they are not without their faults. They do give some trouble, due to plugging of the nozzles, and it is also found that the bearing upon which the arms revolve is not entirely grit proof and is subject to grinding action of the pulp

SCREEN ANALYSES OF TUBE MILL AND CLASSIFIER PRODUCTS AT
TONOPAH EXTENSION MILL

	10	20	60	100	150	200	20
	mesh	mesh	mesh	mesh	mesh	mesh	mesh
Tube mill No. 1 intake (Komata lining).	15.45	16.90	40.00	14.00	4.19	4.62	4.91
Tube mill No. 2 intake (smooth lining).	1.77	1.06	18.08	35.82	14.35	13.83	15.09
Tube mill No. 1 discharge.	1.00	0.80	17.20	26.60	8.60	11.20	35.60
Tube mill No. 2 discharge.			2.60	20.60	14.00	16.80	46.00
Classifier No. 1 overflow.				0.16	1.00	2.8	96.81
Classifier No. 2 overflow.				1.89	5.91	14.60	77.60

which gets into it. Some experiments have been made lately by removing the nozzles from the air and pulp-delivery pipes, which constitute the arms, and it has been found that while the speed of revolution has been diminished, there is no other ill-effect and the agitation continues as usual. This procedure is calculated to lessen the probability of stoppage from plugged nozzles. Another experiment to avoid the wear occasioned by grit entering the bearings and grinding them out has been made by removing the bearing altogether from the tank and suspending it above the tank, connecting it with the revolving arms by means of a pipe. It seems probable that both these variations may be productive of economies, and a final decision on the matter will be of interest.

The power required to move the Trent agitators is stated to be 6 hp. for each agitator, plus the power required for furnishing compressed air, which in this case is 13 hp. for five agitators, including the four treatment agitators and the stock tank.

Vacuum Filtration. From the agitators the pulp is taken to a stock tank, 30×20 ft., which serves to feed the filter. The stock tank is equipped with a Trent agitator to keep its contents in suspension. From the

stock tank the pulp is taken to a stationary vacuum filter of the Butters type having 100 leaves. The filter is operated in the usual way, a cake of $1\frac{1}{2}$ in. is made and given a 2-hr. solution wash. The usual cycle is six hours in total. An additional extraction is made on the filter, which at times reaches 3%. The slime at the Extension mill is easy to filter, as is generally the case with the Tonopah ores.

Zinc shavings are used for precipitation. The solution is clarified by passing it through excelsior and is precipitated in eight 6-compartment zinc boxes, each compartment being $30 \times 36 \times 30$ inches.

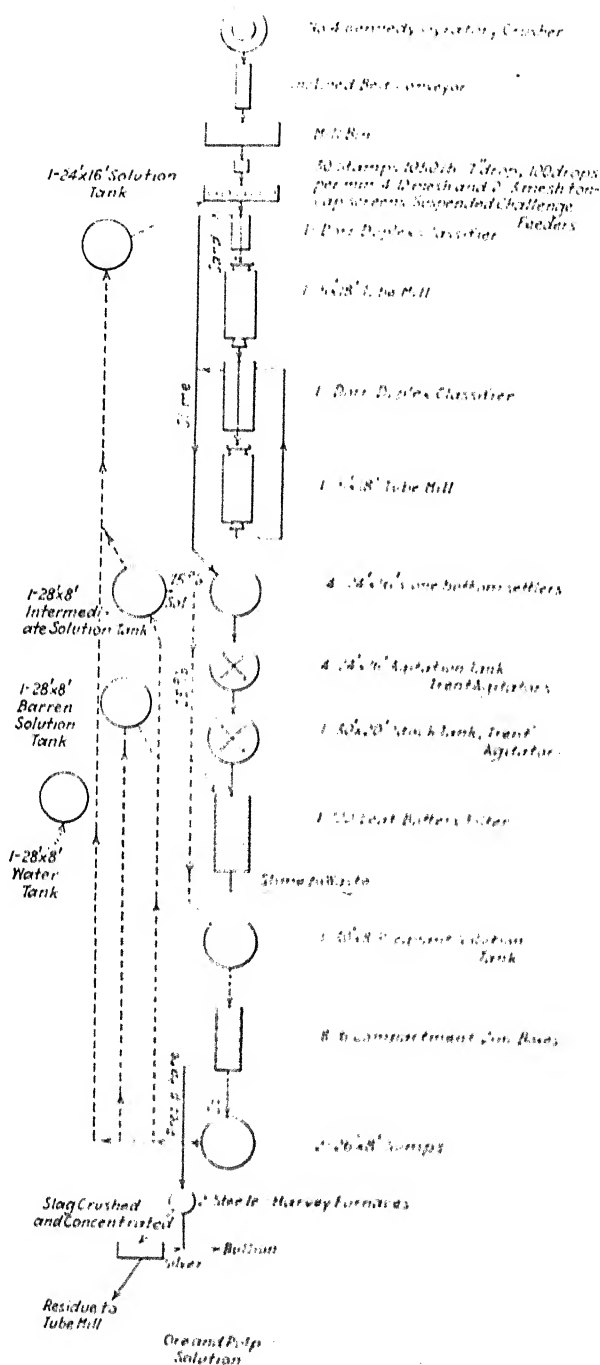
The precipitate resulting is partially dried and fluxed and melted in Steele-Harvey furnaces. The slag is allowed to accumulate until sufficient is at hand for treatment when it is crushed in one of the batteries, concentrated to remove the metallic particles and the remainder added a little at a time to the tube mill, where it is crushed to a slime and cyanided along with the regular mill run of ore. By treating the slag in this manner only a small portion is added to the mill run every day, and it is soon used up without any detrimental effect. It avoids the expense of shipping the material to smelters and it is probable that the ultimate economy of the scheme is as good or better than when it is shipped.

There is some controversy over the relative merits of zinc shavings and zinc dust as a precipitant in the Tonopah district, and the operators at the Extension mill believe that the process using shavings is as satisfactory and economical as when the dust is used. They point to the fact that their consumption of zinc is as low as is usual when zinc dust is used and that their cost of cleanup is no more than in such cases and also that their resulting bullion is better and barren solutions are easily secured. This question is one which will stand a good deal of argument, and there seems to be something of advantage for each system. It is, however, difficult to overlook the great advantage in simplicity and safety obtained by the use of zinc dust. This matter will be referred to again in considering the metallurgy of Tonopah in a general way.

Extraction Data.—The extraction obtained at the Extension is consistently high and may be said to be about the limit obtainable on Tonopah ores. The material treated contains silver and gold in the proportion of about 90 : 1, the heads averaging 16 oz. silver.

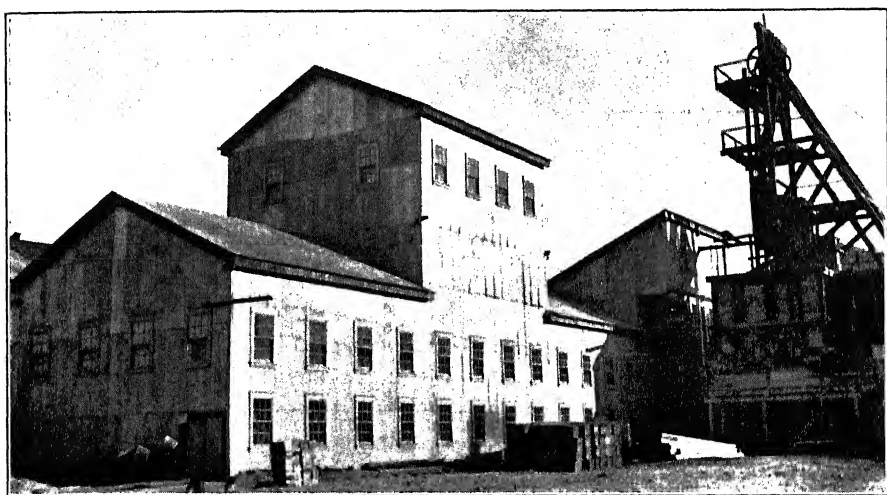
The pulp is given 40-hr. agitation in the tanks with solution of about three pounds of KCN per ton. The extraction obtained averages about 94 to 95% of the total content. As an example of the division of extraction a typical month showed 25.77% in milling, 67.57% in agitation and 1.74% in the stock tank and in filtering. Solutions are warmed at this mill, as is the general practice at all Tonopah mills, to 120° , and it is claimed that a clear and definite additional extraction is obtained over working with normal temperatures.

DETAILS OF CYANIDE PRACTICE



The consumption of material is as follows: Cyanide, 2.78 lb.; lead acetate, 0.963 lb.; lime, 3.398 lb., and pebbles, 4.423 lb., all calculated per ton of ore milled. The consumption of zinc is 0.052 lb. per oz. of bullion recovered. The mill treats about 155 tons of ore per day with 400 hp., and employs 14 men regularly, including the superintendent. The accompanying flow sheet shows the details of the system followed.

An Installation of Heavy Stamps.—The mill of the MacNamara Mining Co. is one of the most recent of the Tonopah installations, and originally contained a number of innovations, most of which, however, have made room for devices conforming to standard practice.



THE MACNAMARA MILL.

The ore is brought into the mill over a conveying and sorting belt, and that part of the waste which is easily recognizable is thrown out. A Kennedy gyratory crusher is used for primary crushing and the ore is then dropped into the battery bins.

There are 10 stamps in the mill, fed by suspended Challenge feeders, the stamps weighing 1400 lb. each. They are set in a special heavy-duty mortar, the screen being only three inches from the dies. This type of mortar is designed for rapid crushing and, in fact, at the MacNamara mill a duty of 7.5 tons per stamp per day is attained. With stamps of this weight this could not be considered an exceptionally high duty, but the crushing capacity is limited by the following regrinding installation which will not permit any greater output. The stamps make 98 drops per minute through 8 in., and the mortars are equipped, one with 8-mesh and the other with 12-mesh screens. The different screens are used with the idea

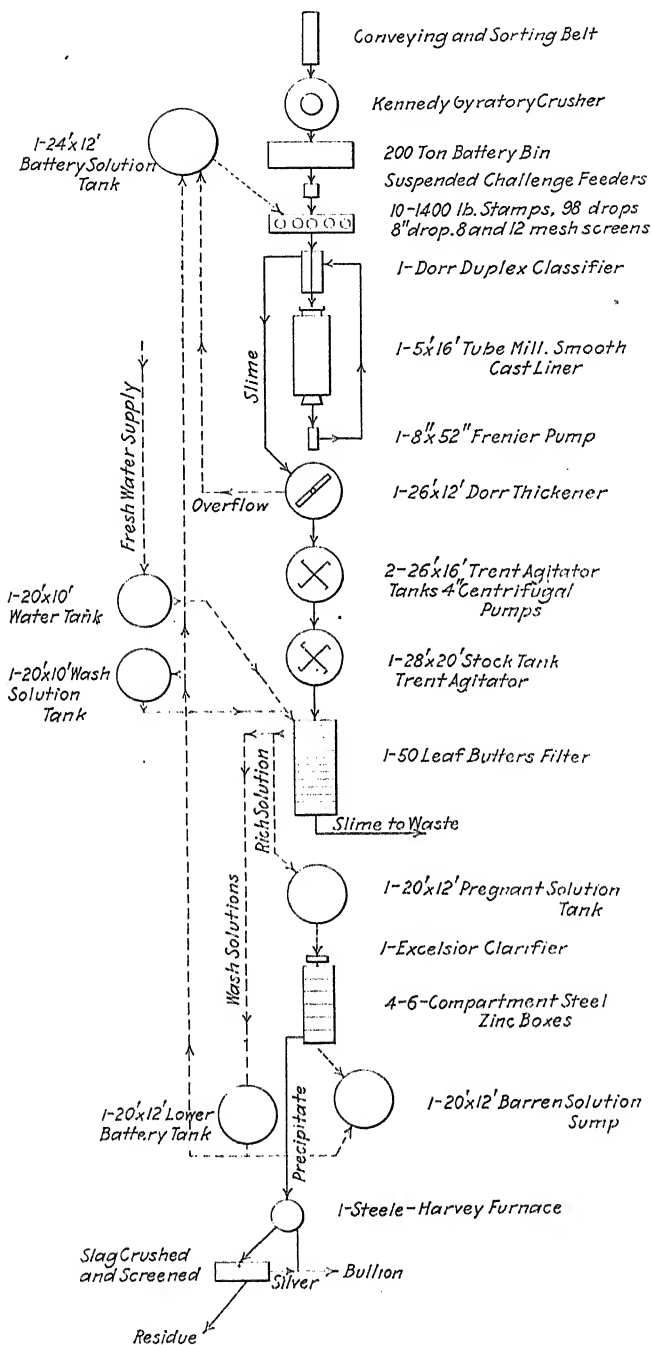
of furnishing a varied feed for the tube mill, as has been mentioned in the case of the Tonopah Extension mill, although the efficiency of this procedure in the case of the MacNamara would seem to be limited by the use of a single tube mill.

The tube mill used is 5 ft. diameter and 16 ft. long, which is carrying the shortness to the extreme. As has been mentioned, the tendency at the present time is to limit the length of the tube mill, and this instances the progression of that tendency. It is stated that with the 16-ft. mill the results are the same, as far as fineness of output is concerned, as if the 22-ft. length were used and the wear on the lining and the power and pebble consumption are less. This mill is equipped with smooth cast lining and runs at 26 r.p.m. and uses about 60 hp. for its operation. The cast lining is stated to wear 11 months, and as it is locally cast, hard iron, the renewal cost is not high. The mill is equipped with a scoop feeder of the spiral type. The discharge is taken up by an 8×52-in. Frenier pump and returned to the classifier, making a closed circuit.

The Agitation System. The slime from the classifier is collected and thickened in a Dorr thickener, 26×12 ft., the overflow solution being returned for battery use and the thickened slime proceeding to the agitators. There are two agitator tanks, each 26×16 ft., equipped with Trent agitators actuated by 4-in. centrifugal pumps of the local make already mentioned. Originally the arrangement of these agitators was somewhat different, the bearing was situated outside and below the bottom of the tank and connected with the revolving arms by means of a pipe which also revolved. This pipe passed through a stuffing box in the bottom of the tank, but it was found that when the gland was tightened sufficiently to prevent leakage, the free revolution was prevented and the agitator was likely to stop at any time. Recourse was had to the standard Trent device and subsequent trouble has been confined to the points previously mentioned.

Agitation in these tanks is continued for a total of 55 hr., which includes the time required for filling the tank. The filling time is 18 to 20 hr., during which the agitators are in use and the pulp receives efficient agitation. A 2-lb. KCN solution is used for treatment.

After the completion of agitation the pulp from the agitators is received in a stock tank, 27.5×19.5 ft., also equipped with a Trent agitator. From this tank the pulp is drawn off to a 50-leaf vacuum filter of the Butters type. In the construction of the tank for this filter it was intended to discharge it from a single point, and the bottom was not divided into separate hoppers, but consisted of a single V-bottom, in which was placed a spiral screw conveyor to convey the discharged slime to the point of exit. This arrangement was found to be decidedly unsatisfactory, as the slime stuck and piled up on the side of the tank and even-



tually the screw was tunneling under the mass of slime. In order to remedy this defect the bottom was divided up into separate hoppers by inclined partitions, and is now conforming to usual construction.

The filter cycle occupied a total of $4\frac{1}{2}$ hr., which includes a 2-hr. solution wash and 5- to 10-min. water wash as final treatment. The cake is formed in from 60 to 80 min., and usually has a thickness of about $1\frac{1}{4}$ in. In common with most Tonopah slimes, this cake is easily washed.

Precipitation on Zinc Shavings.—In accordance with the usual Tonopah practice, zinc shavings are used for precipitation, there being four 6-compartment boxes preceded by a special box containing excelsior for clarifying the solutions. It is to be noted that several plants in Tonopah are using this excelsior clarifying system and it seems to do the work in a satisfactory manner. It is undoubtedly a simple and cheap process and for small plants seems to be a cheaper method than installing clarifying presses. A box is made on the principle of the zinc precipitator box, the size varying with the requirements, and is filled with excelsior through which the solution passes in the same manner as through a zinc box. The excelsior is packed rather tightly and effectually prevents suspended slime from entering into the zinc box. The excelsior is easily and cheaply cleaned when there is sufficient accumulated slime to make cleaning necessary.

The precipitate is partially dried, fluxed and melted in a Steele-Harvey furnace, the slag crushed and screened to separate the metallics which are returned to the bullion melts. A flow sheet of the mill is given, showing in detail the metallurgical procedure.

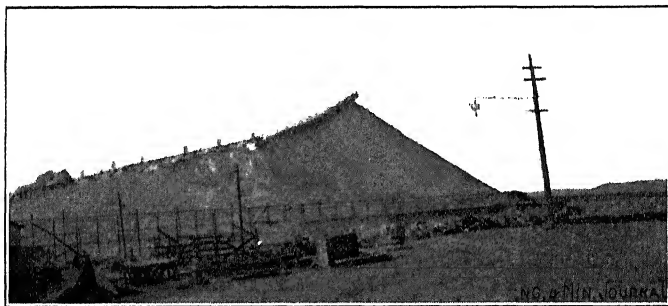
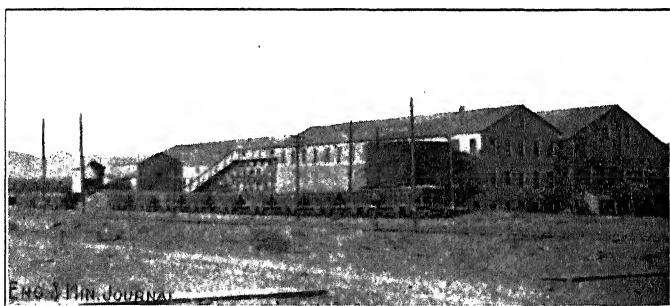
The extraction secured is 90 to 92%, in conformity with that secured by most of the other tube mills of the district. The consumption of cyanide is about $1\frac{1}{2}$ to $1\frac{3}{4}$ lb., and of lime about three pounds. The lime is added to the classifier in dry form. Of lead acetate the consumption is 0.55 lb. per ton milled, and of pebbles, four pounds per ton milled. The mill crew consists of seven men, not including the superintendent.

The MacNamara is the smallest mill in the district and its operating costs are not to be fairly compared to those obtained by the larger mills. It is stated, however, that the costs are not materially more than those of the mills which most nearly approximate its capacity. The mill is situated in the town of Tonopah, and is convenient to sources of supplies and finds it easy to secure labor sufficient for its needs. The details of the treatment are shown in the accompanying flow sheet.

Separate Treatment at the Desert Mill.—Besides the mills in Tonopah proper, there are two that are, or have been, milling Tonopah ores with success. The most important of these is the mill of the Desert Power & Mill Co., at Millers, 13 miles from Tonopah. This has been

reducing ores of the Tonopah Mining Co. for some years, it being the original cyanide mill of the Tonopah district, constructed in 1906. The mill contains 100 stamps of 1050 lb. each and regrinding is performed in Huntington and Chilean mills of the Monadnock type. The ore is crushed in solution, as is the practice in all mills of the Tonopah district, and is concentrated on Wilfley tables in order to recover the sulphides which are not so easily cyanided.

The sand and slime at this mill are treated separately after the older method in use before treatment as total slime became universal. In

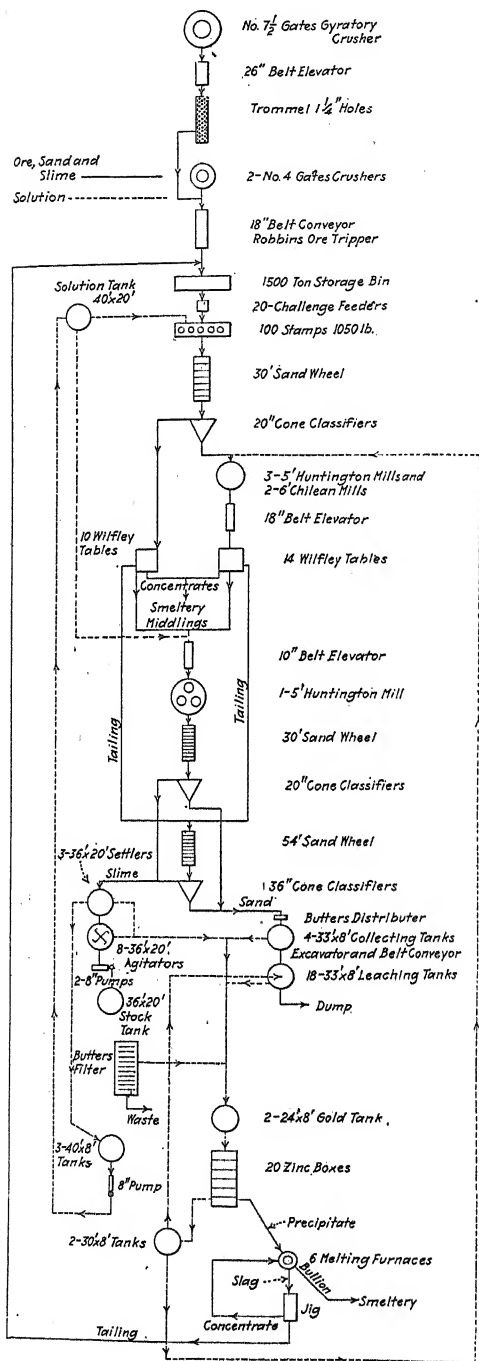


MILL AND SAND TAILING PILE OF THE DESERT POWER & MILL CO., MILLERS, NEV.

this plant the slime is treated in tanks having mechanical agitation by means of revolving arms moved by gears at the top of the tanks. The sand is subjected to double treatment, being collected in 33×8-ft. leaching tanks and afterward removed by means of Blaisdell excavators and distributed with distributors of the same make into secondary leaching tanks of the same type and size.

It is noteworthy that although crushing is in solution and concentration is practiced in the same solution, the amount of metal dissolved during these operations is proportionally small, and it is found necessary to take advantage of every possible means of increasing the dissolution of the metal after that point.

DETAILS OF CYANIDE PRACTICE



FLOW SHEET OF DESERT MILL.

The plant in general is much like the South African plants of an early period, containing tailing-wheel elevators, separate treatment with its consequent large area of tanks for leaching and slime treatment, and comparatively great area under the mill roof. The mill is extremely interesting as a comparison with modern mills of the same or greater capacity now operating in Tonopah and a flow sheet of it is herewith presented. The mill treats 500 tons per day, of which 60% is treated as slime and the remainder as sand, the sand requiring about 15 days' leaching to extract the maximum economical percentage. It requires 770 hp. and 64 men for its operation.

Detailed descriptions of the Desert mill have been published in the technical press, and it is not necessary to review its methods in detail at this item, as they are sufficiently well known. It would, of course, be impossible for a mill of this kind to beneficiate ores at a cost comparable to that attained in modern mills, but it may be said that for a mill of its type, the Desert plant is still performing good work. A comparison of the Desert mill with the new Belmont plant forms a good object lesson as to what great changes have taken place in the cyanidation of silver ores within six years.

At Millers there is also the old mill of the Belmont company, having 60 stamps and built after the separate treatment plan, much like the Desert mill. This mill is now treating a small quantity of custom ore and retreating some of its sand tailing. A description of it would be unnecessary at this time.

DISCUSSION

Cost of Cyanidation at Tonopah

In the synopsis of Herbert A. Megraw's article on "Silver Cyanidation at Tonopah—II," in the JOURNAL of Mar. 1, with reference to the Desert mill at Millers, Nev., the statement is made that, "Costs are higher than those obtained with modern all-slime plants," and in the text of the article, one reads: "It would, of course, be impossible for a mill of this kind to beneficiate ores at a cost comparable to that attained in modern mills."

It is possible that what I believe to be an erroneous impression may be gained from the above statements. If Mr. Megraw refers to the modern mills of Mexico or modern mills of the United States, treating straight gold ore, the statements are correct, but if he would only refer to the mills, both modern and antiquated, of the Tonopah district, which would be a fair basis for a comparison of costs, I believe an investigation would show that the operating costs of the Desert mill, granted to be antiquated, have been, and are still, lower than those of any other mill in the district.

For the eleven months of the present fiscal year the direct costs at the Desert mill are, \$2.489 per ton, indirect \$0.146, total \$2.635 per ton. Direct costs include all labor, power and supplies used in operating the mill together with all costs of repairs, renewals, and upkeep of plant and equipment. Taxes, insurance, legal and home office expense are included in the indirect costs.

A. R. PARSONS.

Tonopah, Nev., Mar. 8, 1913.

It is possible that Mr. Parsons has misinterpreted the statements to which he refers in my article dealing with cyanide practice at Tonopah. What I meant was that a plant operating on the old separate-treatment system, without the most modern machinery and appliances, cannot possibly reach the low level of cost attainable in all-slime plants where every improvement is at hand. Of course, to make any comparisons of value, the scale of operations must be approximately the same, and for this reason the Desert mill, treating 500 tons, cannot be compared to the other mills in Tonopah which handle 150 tons or less per day. An instructive contrast might be made between the Desert mill and the new Belmont mill, which treats approximately the same tonnage of the same kind of ore. Undoubtedly the Belmont, a modern and efficiently operated installation, is treating its ore at less cost than the Desert mill, or will be doing so when normal conditions can be maintained. My statement was not limited to the Tonopah district alone.

I am aware of the cost of milling at the Desert mill and consider it exceptionally low for a mill of that kind. I think Mr. Parsons will agree with me, however, in believing that a mill equipped with every modern improvement can treat the same ore as efficiently and at less cost.

H. A. MEGRAW.

New York, Mar. 18, 1913.

On reading Mr. Megraw's article on "Silver Cyanidation at Tonopah—II" in the JOURNAL of Mar. 1, a reference to the slime discharge of the MacNamara mill will be noted, which seems to condemn that type of installation generally as a method of removal of tailings.

Quoting briefly, he says: "The mill of the MacNamara . . . originally contained a number of innovations, most of which have been made for devices conforming to standard practice . . . The filter bottom was not divided into separate hoppers, but consisted of a single V-bottom, in which was placed a spiral screw conveyor to convey the discharged slime to the point of exit. The arrangement was found to be decidedly unsatisfactory, as the slime stuck and piled up on the side of the tank and eventually the screw was tunneling under the mass of slime.

In order to remedy this defect the bottom was divided up into separate hoppers by inclined partitions, and is now conforming to usual construction."

Though without first-hand knowledge of the conditions prevailing at the MacNamara, I wish to state that this failure of a screw conveyor readily to clean a filter hopper is not to be considered a typical performance, nor should it be a sufficient reason to revert to the common practice.

As evidence, I would submit the results obtained at El Tigre, Sonora, where a screw conveyor is transporting heavy filter slime-cake that is dropped into a hopper that contains no water whatever. The equipment, as first set up, was a screw of ribbon type, revolving in the bottom of a horizontally set discharge hopper, the sheet-iron walls of which are inclined at an angle of 45°. The residues discharged are filter cakes from Kelly presses, which range from 25 to 30% moisture, and more often approach the former figure than the latter. Inasmuch as the cakes are stiff and sticky, the leaves are washed with water from a high-pressure hose, after having dropped the cake by internal water pressure, but the total discharge from the hopper has not exceeded a moisture ratio of 0.5 of water to 1.0 of solids, more frequently being 0.4:1, and there is no accumulation of water in the hopper at any time, to serve as a flushing medium.

When first put in use, the conveyor behaved as described by Mr. Megraw, and "tunneled" through the slime-cake, making the prompt discharge of residues impossible. After some time elapsed, the following alterations were made, which changed the screw from a source of annoyance and lost time, to a smoothly working mechanism. First, the bottom plates were taken out, and a trough, 22 in. wide, was bult into the bottom, of similar gage iron. The hopper bottom was originally level, but this trough has an inclination of 12% on a 50-ft. length.

The ribbon shaft was lowered as well, but not as much, and is now a foot above the bottom of trough at discharge end, while at the other extreme it is only about 5 or 6 in. above it.

The result of the change is that all the slime slides into the trough and is at once cut up by the worm, and pushed forward before it has time to lag and hold back the succeeding fragments of cake that fall. The small amount of hose water that is used acts as a lubricant and the slime cakes shoot out of the discharge end of the hopper as though on a greased skid way.

No fall or head room was sacrificed, as the hopper is at the head of the tailings ditch. In passing, it might be said that without the aid of the screw conveyor, it is impossible to discharge the hopper save by long-continued sluicing with much water. The conveyor is driven by a small

motor that takes about 3 hp. under the new arrangement, and as it is in operation about 4 hr. in all per day, the power requirements are extremely small.

Cake discharges are now made in 15 to 18 min., counting from the time that the presses are opened until the time that they are beginning to fill again with slime. In this time five presses of the "Parral" size are cleaned. Occasional discharges have been made in 10 or 12 minutes.

The above statement shows that screw conveyors will remove filter slime under the proper conditions, even though much denser than the average vacuum filter cake, and at no noticeable expense for power or repairs.

Conditions at El Tigre preclude the use of much water or water in large quantities at recurring intervals. At other plants they might be such as to offer no field for the screw conveyor for a variety of reasons, but it is certainly possible to make it work well as a means of transport for slime cake in a filter plant. Furthermore, it does not leave masses of heavy slime in the corner of hopper, as is frequently the case when using rectangular boxes and dropping the cake in water or barren solution.

DONALD F. IRVIN.

Yzabal, Sonora, Mar. 15, 1913.

CHAPTER XII

PRACTICE AT TONOPAH—Concluded

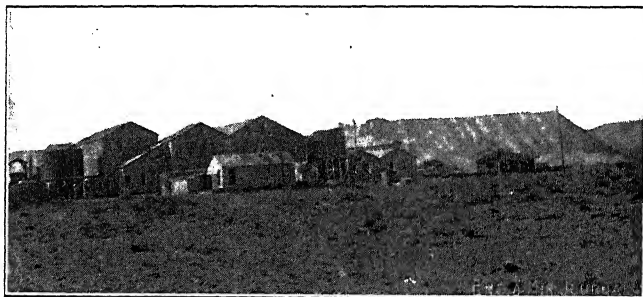
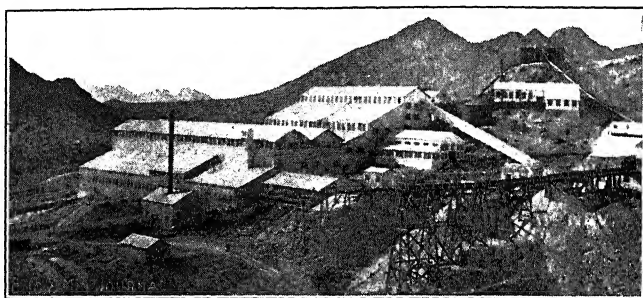
The ores of the Tonopah district have not as yet been subjected to thorough tests in order to determine the advisability of sorting the ore before milling it. Some of the plants have adopted sorting in a desultory way and two have taken some pains to accomplish a more or less thorough sorting. These latter are the West End Consolidated and the new Belmont. The first of these has installed a mechanical washing machine which screens and washes the ore in hot water and then delivers it upon a wide sorting belt running at slow speed. This belt is so arranged that the sorters work on one side of it, throwing the waste not off the belt, but to one side of it. At the end of this belt there is a splitter which bivides the stream delivery, the milling ore going to its proper bin while the waste is delivered into a waste bin from which it can be readily discarded.

There are several advantages about this sorting system. The ore to be sorted is passed over a trommel with small holes and is given a thorough rasping which dislodges much of the sticking clay and mud and also gets rid of the fine portion of the ore which does not require sorting but which goes directly into the mill. The coarser ore thus is passed through into the washer proper, which is a large steel cylinder set on an incline with its lower, or receiving end, set into a tank of water which is heated by steam. The inside of the cylinder contains a spiral, or reverse screw arrangement, which obliges the ore to ascend through the cylinder until it is finally discharged at the higher, or discharge end. Near the discharge end there is a section of the cylinder perforated with small holes through which the washing water returns to the tank below. The coarse ore delivered to the sorting belt is in perfect condition for sorting, as the operator can see at a glance its character and can eliminate all absolute waste without hesitation. The mud and clay washed from the ore are collected in the washing tank and can be recovered at convenient intervals. It is usually of high grade and is sent to the mill along with the regular milling ore.

The practical utility of this system has been thoroughly tested and calculated at the West End plant and the conclusion is that there is a clear and definite saving by its use. A large portion of rock that will not pay its way through the mill is discarded, saving the milling cost of putting it through the process and enriching the portion of payable ore.

bulk for milling, the economies being evident. The new Belmont mill has installed a similar machine for washing the ore.

Sorting in some form is practiced by several of the operating companies at Tonopah, but only at the above mentioned plants is it carried out in thorough form. It has been stated that a great many of the Tonopah dumps would pay well for sorting them over if it were possible to lift the material economically and get rid of the waste. If this statement is true, it seems likely that sorting while the ore was originally in motion might have repaid the trouble necessary to do it. It is a question which requires some study and it is impossible to make any statement which would certainly cover all cases.



NEW MILL AT TONOPAH, NEV., AND OLD MILL AT MILLERS, OF THE TONOPAH-BELMONT DEVELOPMENT CO.

Crushing in Solution.—All the operating mills at Tonopah use solution throughout the mill operations. At the same time there are certain of the operators who believe that better metallurgical results could be obtained if it were possible to do the crushing and grinding in water without incurring a loss of cyanide and dissolved metal. It is evident that in treating silver ores where solution of comparatively high cyanide content must be used, crushing in water is not usually practicable. The amount of water taken in unavoidably from the grinding system to the

cyanide plant would have to be discharged as moisture with the residues, and at that time would contain both cyanide and metal in solution, a combination that could not be thrown away. The only system by which it might be managed would be to filter the pulp from the grinding system, whereby it could be introduced into the cyanide plant with approximately the same quantity of water as the residues would contain in moisture. Whether the advantages obtainable would justify the additional expense is a question which would have to be solved in each particular case. The procedure is followed at the mill of the Smuggler-Union Mining Co., at Telluride, Colo., as has already been mentioned in these papers.

Crushing in Water at Goldfield.—The advantage of crushing in water is believed to be a saving of cyanide by removing cyanicides from the ores, resulting also in an improved extraction. This matter has received much attention from the operators at the Goldfield Consolidated mill and experiments covering several months' work have convinced them that water crushing has decided advantages over crushing in solution. Naturally enough, the conditions at the Goldfield mill are decidedly different from those obtaining at Tonopah and the results of experiments cannot be transferred bodily. The former is treating a gold-bearing ore and using solutions much weaker than those necessary for the ores of Tonopah.

At the Goldfield Consolidated, it has been satisfactorily proved that when crushing in water is followed the consumption of cyanide is less and the extraction of metal better than when crushing in solution. It is shown, also, that when crushing in solution is practiced, there is likely to appear in the mill a light gelatinous product which refuses to settle and causes a great deal of trouble in mill operating. The substance appears much like an alumina product, which it may be, but that has not been proved. On the contrary, when water is used in the crushing system, this product does not appear.

It is extremely difficult to account for this difference and many theories have been invented in the attempt to do so. The theory has been advanced that no matter how alkaline a crushing solution may be, and all solutions containing cyanide must be kept alkaline, there will be a certain length of time, however short, when the acid liberated from the ore will overbalance any alkalinity immediately available at any one point, and that during this short time a chemical change might take place which would render soluble some elements which would not be put into solution with water and which would be removed by washing before reaching the cyanide department, were water used in crushing. This momentary acid condition might also introduce certain combinations prejudicial to high extractions. Of course, there has been no research which would prove that this condition does exist and is responsible for the results shown, but the results are plain. Commercial operators rarely have

the opportunity to solve questions of this kind, but it is just such problems which most need solving in the cyanide field.

Whether or not similar conditions to those found at Goldfield would obtain at Tonopah is not certain, but with this example in mind there are many who would like to have the opportunity of trying it.

The use of gravity stamps for crushing is universal at Tonopah and it seems that nothing else has been considered in the design of the plants. This seems unfortunate, for the ore does not appear to be too hard to give good results with rolls or chilean mills, either of which might be applied with economy. It is true, however, that stamps have been considered the conservative crushing machine for a long time and the design and construction of plants at Tonopah have been eminently conservative. To install a machine which will surely do the work, even though at a cost somewhat higher than that of one which might be satisfactory, is a sound basis upon which to reason and designers can hardly be censured for following that system. At the same time the results obtained by the other machines, rolls and chilean mills, both as to efficiency and cost, are no less definite and clearly proved, the obstacle to their use being simply that the results are not so well known. One cannot say with certainty that either of the machines above mentioned would satisfactorily take the place of stamps at Tonopah, but it is not too much to say that I believe either of them would introduce economies.

Lining for Tube Mills.—The matter of tube mills at Tonopah introduces some interesting variations which are worthy of attention. First attention is called by the shortness of the mills generally used, especially in the later installations. This progression has apparently been along conservative lines and there is reason to believe that the theory is sound. Certainly it has resulted in a reduction of power for the same production.

The mills recently installed are generally 5 ft. diameter and 18 ft. long, in one case the length has been reduced to 16 ft. with satisfactory results. It will be interesting to watch this development and see what it brings forth. It is not impossible that the tube mills of the future may be more like drums of large diameter and short length than the long, narrow tubes first used.

The lining of the tube mills has given rise to much argument. The contrast here to Mexican practice is noteworthy. In all the Tonopah installations I have not seen a single instance of the use of the El Oro ribbed lining, but everywhere there is the use of the smooth cast lining and the sillex blocks, both of which had been tried and discarded in Mexico before the El Oro lining came into use. The smooth cast lining would seem, theoretically, to be the most inefficient of all possible linings, as it would appear that the pebbles would be more than likely to slide over it and reduce the ore by rubbing it between the lining and the

pebbles. The matter of the dropping or tumbling of pebbles would apparently be reduced to a minimum, and while it is clear that the power requirements would be reduced to the lowest possible point, apparently the efficiency would go down with it. That this is not the case is what several of the operators declare positively. They claim to get better results, both as to character of product, its quantity and cost of production. And it is also stated positively that the pebbles do not wear flat in the smooth-lined mills. It is a fact that if one is careful he can avoid seeing flat pebbles on the scrap heaps of these mills.

The silex lining has its advocates also, the installation at the new Belmont mill containing silex lining except in experimental cases. Silex has proved to be a good lining in many cases, and except for the item of cost has done good work in Mexico. The objections there to its use are the cost and the time necessary to reline the mill when it wears out. This usually puts a tube out of commission for from five to seven days and where there is no reserve capacity it seriously interferes with the mill operation.

The Komata lining has had trials at Tonopah and in the case noted in the Tonopah Extension mill, is doing satisfactory work. Komata linings have also been installed at the Goldfield Consolidated with satisfactory results and are now used altogether. It is claimed that these linings increase the power consumption, which is undoubtedly true, but that the ultimate efficiency is increased. This is even more definitely shown when the revolutions of a mill into which they are placed are reduced considerably. For instance, a 5×18-ft. tube mill using smooth or silex lining and revolving at 26 or 27 r.p.m. can be reduced, when the Komata lining is used, to about 22 or 23 r.p.m., resulting in a lower power consumption and no great reduction of efficiency.

The height at which the load of pebbles is carried also varies a good deal. The variation is from somewhat below the center line of the mill to 6 or 8 in. above it, calculating with the mill not running, of course. In cases where the load is carried above the center line of the mill a grating has to be used in the discharge in order to prevent the issuing of pebbles. At the West End mill a difference of pebble load made an enormous difference in the efficiency of the tubes so that the whole mill was affected. This question of lining will probably be solved in the near future when there will be some agreement among the operators as to which type best suits their needs. At present there seems to be a great difference of opinion.

Types of Agitators.—Opinions in regard to agitators seem to differ as widely as they do in tube-mill linings. There are examples of the Pachuca, Hendryx, Trent and other systems in use. The original mills of the district, the Desert and Belmont mills at Millers, used mechanical

agitators for their slimes, the Hendryx type is in use at the Montana-Tonopah mill and several installations are using the Trent system, while the new Belmont mill at Tonopah is using the Pachuca system.

Particularly the Trent agitator seems to be a bone of contention. Some users say it is perfect and others declare it has no merit in it, that it is a nuisance and not satisfactory in any way. The truth lies somewhere between these two extremes, no doubt, but at what exact point is impossible to state.

The Hendryx agitator has been previously mentioned in these columns, but it is a machine which has never become popular on account of its high power consumption. There is no doubt that it is a good agitator, but it will probably never become a serious factor in the agitation of slime for the reason of its high operating cost.

Pachuca tanks have been the subject of investigation for some time and many operators claim that they offer no advantages in economy nor in additional extraction obtained.

Referring back to the new Nipissing mill at Cobalt, in which the slime agitators are the old-style mechanically moved arms, the designers stated that they had been able to find no device which would assure them either better results or lower costs. In such event the Pachuca tank would be entirely out of the reckoning, for if it presents no such advantages, its high cost of installation and the additional cost of pumping in a mill, occasioned by the height of the tanks, would certainly preclude its installation. I am of the opinion that the Pachuca tank is likely to be replaced by some other more satisfactory design.

Concentration Practice.—It will be noticed that some of the Tonopah mills practise concentration while others do not. The two at Millers, the Montana-Tonopah, the West End and the New Belmont practise concentration, while the Tonopah Extension and the MacNamara mills do not. In those mills which do concentrate, the object has been to make as little concentrate as possible consistent with removing the objectionable elements from the ore. With low- or medium-grade ores concentration is not necessary but with the rise in silver content, attendant upon the increase in the proportion of sulphides, concentration must be resorted to. Many of the mills using the process have reduced the number of tables, the point being that it is more expensive to market concentrate than bullion; therefore as large a proportion as possible should be taken out in bullion form. This is sound reasoning, particularly where the concentrate has to be shipped to smelters where losses may be multiplied by many means.

There is no instance of local treatment of concentrate at Tonopah. In this connection it is interesting to review the situation at Goldfield, where the Consolidated treats all of its concentrate by an elaborate proc-

ess. Experiments on concentrate treatment showed that by treating the concentrate raw a certain percentage could be saved; that by first roasting the concentrate and then cyaniding it, a better extraction would result, but that by treating it raw, then roasting it and retreating by cyanide, an extraction about equal to the sum of the results of the other two methods could be obtained. That system has been installed and is followed with success. After the cyanidation of the roasted concentrate, the residue is delivered into the tank which feeds the filter and is discharged with the filtered tailing. By this means the concentrate tailing is reduced to a value nearly equal to that of the regular mill tailing. The process is interesting and unusual.

Use of Heated Solutions.—Operators universally agree that the extraction of silver from the Tonopah ores is increased by heating the solutions. The point to which this is carried is generally about 120°. There seems to be no difference of opinion on this point and all the mills are doing this with good results. The question naturally occurs as to whether the Mexican operators have been overlooking anything in the matter of heating solutions. I have seen the scheme tried several times and made experiments on it, but without any beneficial result. That this is not unusual will be shown in a later paper, when I will call attention to another silver mill which has made repeated experiments and found no increase of extraction through heating the solutions. Still, this is a point which ought to be worked out for each particular ore, no general rule governing it.

Heating solutions seems to have no effect whatever on the extraction of gold. This means, of course, solutions of normal temperature, as extraction of both metals falls off in abnormally cold solutions.

The use of lime and lead acetate at Tonopah does not vary widely from accepted practice at most other camps. The addition of these materials varies, and the practice is governed principally by convenience. The filters in use at Tonopah are all of the stationary vacuum type. The present condition of the filter problem makes it advisable for discussion to be postponed until there shall be more liberty to publish statements.

Calculation of Extraction.—At Tonopah, as in most of the mills at the present time, the calculation of extraction is performed by using the content of bullion produced plus the content of tailing discharged as the value of head samples. Some of the older operators look with envy on the mill men of the present day and think of the monthly recurrence of attacks of heart disease that came with the attempt to reconcile production and tailing content with head samples taken at or before the batteries. Extractions of 120% were not unusual in those days, nor were drops to 60 and 70% unexpected, but the mill man was continuously in

hot water about it, particularly if he differed with the general manager about the accuracy of the head samples. This later method is much simpler and tends to avoid worries. At the same time it is hard to agree with a method of solving a problem by means of which any answer is the right one. I am anxious to have this matter discussed and hope that there will be someone kind enough to take it up and extract opinions about it.

DISCUSSION

Silver Cyanidation at Tonopah—III

In Mr. Megraw's article, "Silver Cyanidation at Tonopah—III," in the *JOURNAL* of Mar. 8, 1913, it is suggested that crushing in water might be accomplished without an additional or prohibitive cyanide loss if the pulp were filtered after grinding, introducing it into the cyanide plant at practically the same moisture contained by the residue on discharging. As the amount of water taken into the mill without building up the quantity of solution is governed entirely by the amount of moisture contained in the residue at the time of discharging, and can only be equal to this amount, the water added ahead of cyanidation would preclude the use of water for final wash. It would allow the discharge to go out containing 33% of standard cyanide solution, which is in our case three pounds per ton of ore. When the cost of dewatering with filters is considered together with the mechanical loss of cyanide, and the trouble and expense of again thoroughly mixing a pulp dewatered to such a point of dryness, the additional extraction above 94.44%, the average obtained by the Belmont Milling Co. for the last eight months, it would hardly seem to be an attractive undertaking, even when considering the cyanide which might be saved by crushing in water.

As to the mechanical-stirrer type of agitator being efficient on silver sulphide ore, I will state that the type of agitator called the "Butters" was originally installed at our Millers plant and only a fair extraction could be obtained from it until a 6-in. air lift was added, taking pulp from bottom of the vat and discharging it over the top, in addition to the mechanical stirring.

At the Tonopah mill where solution during agitation is kept at 100°, the air for agitation is furnished by a steam-driven compressor and the exhaust steam is used for heating the solutions. As there is only 7% loss between live steam at 125-lb. pressure and exhaust at five pounds, in heating efficiency, we can figure only 7% of cost of producing steam against agitating medium or method, so that if air were not beneficial to extraction, and I am of the opinion that it is, another method or medium could hardly be had at the same or lower cost per ton.

At the Millers plant where live steam is used for heating solution, the cost averages about 18c. per ton, while at the Tonopah plant, with, of course, a better equipment, heating and air for agitation together amount only to 12c. per ton of ore treated.

The benefits to be derived from the heating of solutions used with Tonopah ores, are shown in the following tailing assays from tests made identically, except in temperature. They typify the results obtained in practical mill work.

Warm solutions, 100°

48 hr. 0.015 oz. Au. 2.1 oz. Ag.

60 hr. 0.01 oz. Au. 1.4 oz. Ag.

Cold solutions, 65°

0.02 oz. Au. 3.8 oz. Ag.

0.02 oz. Au. 3.0 oz. Ag.

I think that Mr. Megraw's assertion that the addition of lead and lime in Tonopah practice is "principally by convenience" is a little broad. In this mill at least, the lime content is very closely watched, it having been proven, not only by laboratory tests, but on a working scale, that extraction is very erratic, due to reprecipitation when either too high or too low alkalinity is carried. The lime is maintained between 1 lb. and 1.5 lb. of CaO per ton of solution.

The amount of lead giving best result is at all times somewhat of a conjecture, but in order that it may not be understood that lead is added at random and that we have some fixed ideas, even though they may be wrong, the practice and theory followed at this plant are here stated.

It is figured that sulphur, alkaline sulphides, and other reducers have a retarding action and are detrimental to the highest dissolving power of the solutions, and in order to keep alkaline sulphides under control, lead acetate is added to precipitate the lead sulphide. The amount used is determined by experimental tests with clean solution. Zinc in solution will act to a great extent, especially in hot solution, the same as lead, forming zinc sulphide, but is not as amenable to the combination as lead. If an excess of lead is present the zinc will tend to accumulate in the solutions, and then the amount of lead is reduced, allowing the zinc to take care of the alkaline sulphides. In this way a kind of a balance of zinc contents is maintained.

In regard to tube-mill lining, 14 tests, under varying conditions of feed and moisture, conditions in both mills being as nearly identical as possible at all times, showed an average of 5% more product of minus 200-mesh with silex than with the smooth iron liner.

In regard to El Oro lining, which according to Mr. Megraw's Mexican experience is an improvement over all other linings, and which he intimates has never been tried at Tonopah, I think he failed to go thoroughly into what had been tried or considered, and why, in the opinion

of the operator, the practice being followed is best suited to their conditions.

The Montana-Tonopah Mining Co. tried El Oro liners, finding their life to be between seven and eight months, while the cost of the lining installed was over twice that of silex. At this plant the cost of silex lining per mill, when lining seven mills, was as follows: Labor at \$4.50 per day, \$42.25; cement, 28 sacks at \$1.035, \$28.89; silex, six tons at \$42.80, \$256.80, or a total of \$327.94. To Mar. 20, these mills have been in operation eight months, crushing 13,269 tons per mill, or an average of 55 tons per day with the following average discharge screen analysis: On 100-mesh, 1.33%; on 150-mesh, 5.05%; on 200-mesh, 6.42%; through 200-mesh, 87.20%. This is an average of 36 tests made during eight months.

To this date none of these mills has had to be relined, but it is figured that the first mill will have to be lined in about two weeks and the entire installation during the next 60 days. Allowing eight months, which is very good life for this style of liner, the cost compares more than favorably with any available figures of El Oro liners. In "A Textbook of Rand Metallurgical Practice," Vol. II, p. 151, the following statement is made: "While the El Oro liner has a longer life than the silex liner, the difference is not great enough to compensate for the extra cost."

In the original plans for our Tonopah mill, rolls were seriously considered by comparison of all data to be had at that time and were only abandoned after an extended visit to Mammoth Copper Co.'s plant at Kennett, Calif., where 27,000 tons of Belmont ore were sampled as custom ore and crushed with rolls. The excessive wear of roll shells and total cost per ton resulting in the eminently conservative installation of stamps. The general manager of one of the late large cyanide mill installations, where rolls are used, told the writer after six months' operation, that he was sorry stamps had not been installed instead of rolls.

A. H. JONES.

Tonopah, Nev., Mar. 18, 1913.

In this letter, Mr. Jones adds some interesting facts to the discussion of cyanide problems and his statements will be accepted as authoritative on Tonopah practice. Except in those instances where he has misinterpreted the meaning of my remarks, we are substantially in accord.

Regarding crushing in water, I agree with Mr. Jones' reasoning. In my article, the matter is referred to in a discursive way and not as a recommendation. Reference to the article in question will show this.

The remarks on agitators and temperature of treatment solutions are interesting additions to the general data on Tonopah practice.

Mr. Jones' objection to my remarks referring to addition of lime and lead acetate is justified by his misinterpretation of the text of my article. "Principally by convenience" referred to the method of addition, not to the quantity of the chemicals used.

Regarding tube-mill lining, it seemed worth while to call attention to the difference between practice at Tonopah and in Mexico. I did not attempt to convey the impression either that the El Oro lining was the best, or that it had not been tried at Tonopah. What I wished to say was that it is not considered the best in Tonopah and is not in use there, although it has been proved by repeated tests to be best suited to conditions in some other districts.

Stamps versus rolls may be the subject of interesting and lengthy discussion. I hope that Mr. Jones may be induced to publish the facts and figures which led to the decision in favor of stamps at the Belmont mill. Some others have adopted rolls and do not announce any regret.

H. A. MEGRAW.

New York, Mar. 24, 1913.

Crushing Tonopah Ores

The following data relative to crushing Tonopah, Nev., ore by rolls may be of interest in the discussion of the subject invited by H. A. Megraw in his article, recently published in the JOURNAL. A set of 10×30-in. Allis-Chalmers rolls was among the equipment of the crushing and sampling department of the Desert Power & Mill Co. These rolls were in operation four years, from December, 1906, to January, 1911, and during that time reduced 29,873 tons of ore, which was 5% of the entire tonnage, cut out by a Snyder sampler. The roll feed was the same as that going to the stamp batteries, varying in size from slime to pieces of ore 2 in. in diameter, this size depending upon the condition of the 4D crushers. The maximum size of the roll product varied between $\frac{1}{2}$ and $\frac{5}{8}$ in., depending upon the opening between faces of the rolls. However, usually the reduction would be about 50%. The average time run per day was 5 hr. for a total of 1195 days in operation.

The power is estimated at 10 hp. and on that basis would amount to a total of 44,573 kw.-hr., which, at \$0.0152 per kw.-hr., gives the total power cost \$677.52, or \$0.0227 per ton of ore reduced by rolls. It is estimated than one-fourth of one man's time at \$4.50 per 8-hr. shift, or \$0.703 for five hours, a total of \$840.09, or \$0.0281 per ton, is a fair allowance for the labor of operating the rolls during the 1195 days. Roll shells were refaced in a lathe and five changes were made; $2\frac{3}{4}$ sets were worn out during the period of operation. The roll shells weighed

757 lb. each, so that the total consumption of steel amounted to 4163.5 lb., or 0.14 lb. per ton of ore reduced. The rolls were operated at 103 r.p.m., which gives a peripheral speed of about 800 ft. per minute.

REPAIR COST FOR ROLL OPERATION

Labor changing rolls @ \$20.00, per set.....	\$100.00
10 roll shells turned, 6 hr., each @ 69 cents per hr.....	41.40
80 ft. of 10-in. belt @ 96 cents.....	77.20
General repairs to feeder, belt liners, etc.....	100.00
8 bearings babbitted @ \$5.00 for labor.....	40.00
Cost of babbitt @ \$10.00 each.....	80.00
2½ sets of shells @ \$146.62 per set.....	\$403.20

Total.....	\$841.80
Per ton of ore reduced.....	0.0282

SUMMARY

	Total	Per ton reduced
Repairs and upkeep.....	\$841.80	\$0.0282
Labor of operating.....	840.09	0.0281
Power used.....	677.52	0.0227
Total.....	\$2359.41	\$0.0790

It will be noticed that some of the above figures are based upon estimates, but it is believed that the estimates are liberal. I have had the impression that rolls can be used to advantage in the milling of Tonopah ore and am of the opinion that a thorough test and comparison would show a saving in initial cost of installation as well as in operating expense, and would welcome the publication of the figures obtained by A. H. Jones when he was investigating the subject of roll crushing before stamps were decided upon for the new Belmont mill.

A. R. PARSONS.

Monrovia, Calif., May 13, 1913.

Calculation of Extraction

In the third article on "Silver Cyanidation at Tonopah," by Herbert A. Megraw, in the JOURNAL for Mar. 8, 1913, there is expressed some doubt as to whether the method of calculating extraction is better than the old system based on samples of the mill heads. We are familiar with the trouble between the millman and the general manager when the head samples indicate extremes of extraction varying from 70% to 120%, but it is my opinion that the fault lies not in the mill, but in the assay office.

When treating a gold ore it is possible, due to the slight mixing the

samples receive in crushing from $1\frac{1}{4}$ in. to the size that will pass a 60-mesh screen, for a particle of gold the size of the screen opening to pass in excess into the final assay sample or to be retarded and thrown away with the discard, causing an appreciable error in either case.

A 60-mesh Tyler screen has an opening of 0.221 mm., and the cube of this aperture is 0.01079 cu.mm. Assuming the gold in the ore to be 700 fine, silver, 250, and base, 50 (sp. gr. 7), then the specific gravity of the gold as it goes into the assay will be 16.61, and the value of the same per ounce, \$14.62, when the silver has a value of \$0.60 per oz. The weight of one of the cubical particles of gold that will pass a 60-mesh screen would be 0.01079×16.61 , or 0.1792 mg. For assay 29,166 mg. is taken, and if a particle of gold the size of the aperture passes in excess into the final assay sample, or is retarded with the discard, there is 0.1792×14.62 , or a value of \$2.62 difference from the true assay, representing .26% on \$10 ore.

In an all-sliming plant the screen tests will usually show about 80% through 200 mesh, 19 to 20% on 200 mesh, and 1% or so on 100 mesh. The tailing sample is certainly more intimately mixed in its passage through launders, agitators and filters, than would be economically possible for the head sample. For comparison I shall assume the cubical size of the screen opening, although it is certain that with effective treatment the metal in tailing is not fully exposed to the dissolving effect of the cyanide solution, but exists in the grains of quartz or sulphide in quantities much smaller than the inclosing grains. The cubical opening of a Tyler 200-mesh screen is 0.0004052 cu.m., and its weight, if a gold cube, 0.00673 mg., with a value of \$0.098, 80% by weight being taken as through 200 mesh, the value affecting the sample is \$0.0784. The cubical opening in a 100-mesh screen is 0.002744 cu.mm., and its value is \$0.67. This, with 20% of the sample on 100 mesh, gives a value which may affect the final result of \$0.13. The small portion on 100 mesh, all of which will pass 80 mesh, cannot account for a difference of more than \$0.01. The sum total giving a value of \$0.22, which would have an effect of only 2.2% on extraction.

Having shown the value of the particles, it would not be amiss to show the number of sand and gold particles in each case, and their proportions. The specific gravity of tailing being about 2.6, the weight of a cubical particle that will pass a 60-mesh screen is 0.01079×2.6 , or 0.02805 mg. In one assay ton there are 1,039,809 possible particles of this size. In ore assaying \$10 and bullion worth \$14.62 per oz., we have 0.684 mg. in one-assay ton, which divided by 0.1792, gives 3.817 particles of gold. Having 3.817 particles of gold that will pass the 60-mesh screen, there will be, to complete the assay ton, 1,039,785 particles of sand.

In the case of the slime the value is assumed proportional to the screen tests by percentage. With a total value of \$0.50, the value of the minus 200-mesh material is \$0.40, and the weight 25,332.8 mg. The weight of a gold cube equal in size to the aperture in a 200-mesh screen is 0.00673 mg., and \$0.40 represents 0.02736 mg. Therefore, there are 4,065 particles of gold, and, consequently, 25,327.735 mg., exclusive of the gold. Then 25,327.735 divided by 0.0004052×2.6 gives 24,083,772 particles, exclusive of the gold.

With 19% on 200 mesh, the weight is 5541.5 mg., and the weight of the gold cube the size of the screen opening is 0.04558 mg., giving actually 0.1462 particles of gold in this part of the sample; 5541.54 mg., minus 0.0065 mg., gives 5541.5335 mg., which, divided by 0.002744×2.6 gives 776,734 particles, exclusive of the gold.

On 100 mesh there is 1% containing \$0.005, and weighing 0.00034 mg., the cubical opening of an 80-mesh screen is 0.005178 cu.mm., and the weight of the same cube of gold is 0.0756 mg. Therefore, 0.00034 divided by 0.0756 gives 0.0045 particles of gold, which may remain on 100 mesh. There are then 291.66 mg. minus 0.00034 mg., or 291.6596 mg. of sand, and 291.6596 divided by 0.005178×2.6 , or 21,664 particles besides those of the gold.

To sum up these facts, we have, in heads, 3.817 particles of gold, and 1,039,785 particles of sand, or a ratio of 1 to 271,800, and in tailing 4.2115 particles of gold, and 24,882,170 particles of sand, or a ratio of 1 to 5,908,000. From the ratio of gold particles to sand particles, the chances of having an error in the head sample as compared with the tail sample is about $21\frac{1}{2}$ times as great.

Of the usual head sample only one is taken, while with tailing a sample is generally taken from each cycle, at least four samples a day, and any discrepancy in one is partly compensated by the assayer when he takes the mean of the four.

Tons stamped, and tons discharged may not be the same, but under proper operating conditions the results over a period of 12 months will not indicate enough of a difference to justify a suspense account.

Providing there are no mechanical wastes of slime or solution, except in the regular filter discharges, then the value of bullion, plus the value of tailing discharged, divided by the number of tons treated, should give a closer true value of each ton of ore than the older methods.

A. G. CADOGAN.

Puntarenas, Costa Rica, Apr. 25, 1913.

In the JOURNAL of Mar. 8, 1913, H. A. Megraw, in his article, "Silver Cyanidation at Tonopah—III," states that in most of the mills there, the

calculation of extraction is performed by using the content of bullion produced plus the content of tailing discharged as the content of head samples. This, no doubt, is excellent from the point of view of the millman in charge of the plant and doubtless saves him much worry, but from the point of view of accuracy it leaves something to be desired.

There may be serious errors constantly occurring, which, with the above-mentioned method of calculation, would never be suspected. Quite considerable quantities of bullion might be stolen and no one be any the wiser. Moreover, there is no way of finding out if there is any serious unnoticed leakage in the plant.

No doubt the assayer can be checked with duplicate samples, but the greatest test on his work and on the tonnage calculation is whether the output of bullion tallies with the theoretical quantity required. With careful work there should be no reason why the bullion output should not check within reasonable limits. This gives satisfaction to every one concerned and then, should there be any serious discrepancies, the cause will probably be noticed almost at once, whereas with an adjusted method, such as that used at Tonopah, there can only be an accumulation of error.

The fact of crushing in solution complicates the mill-head sample slightly, owing to metal being dissolved while in the mortar box, and also by the bullion content of the cyanide solution in circulation. However, a fair sample of the mill-head can be obtained from the pulp on leaving the mortar boxes. If this is assayed, and also the solution before and after it comes in contact with the ore, the proportion of solution to ore being known and its bullion content allowed for, the original content of the ore can easily be calculated. The pulp, of course, will have to be washed before assaying.

Extractions varying between the limits of 60% and 120% are certainly annoying, but this sort of thing is almost inevitable. However, these variations only happen from month to month and the important matter is what the annual result is going to be; the monthly reports are only to see how the production is progressing. It stands to reason if for several months an unusual quantity of bullion is taken from the zinc boxes and extra zinc acidied, which usually happens at the end of a financial year in order to balance accounts, that the actual production for those months will be in excess of the theoretical.

Later, owing to less short zinc being present in the boxes, the bullion distributes itself over a larger proportion of long zinc than usual, with the result that not so much bullion is cleaned up and there is an apparent shortage. Conversely if there is an apparent shortage of, say, 20% on a 90% extraction, if calculations are correct and there is no other source of error, there is no reason why a month or two later, taking the extraction

as being 90%, there should not be an actual extraction of 110%, making up for the original 20% left in the boxes. About the middle of the financial year, the boxes would be in normal condition and one would expect the theoretical and actual extractions to be about the same.

Taking the year 1912 at the Mijnbouw Maatschappij Ketahoen, the cyanide plant treated 47,597 tons of ore with a total content of 7160.7 oz. gold for a theoretical extraction of 88.7%, calling for 6350.55 oz. The actual gold recovered was 6325.22 oz., or an actual extraction of 88.3%, the difference being 25.33 oz. The silver called for was 19,315.46 oz., whereas 19,224.46 oz. were recovered, a shortage of 91 oz.

Monthly actual extractions varied between 59.5% and 123.3%. This has also been the case for the years 1909, 1910 and 1911 with equally close yearly results.

GEORGE SIMPSON, JR.

Mijnbouw Maatschappij Ketahoen.

Lehong Soelit, Benkoelen, Sumatra.

May 1, 1913.

An article, by Herbert A. Megraw, in the JOURNAL of Mar. 8, on "Silver Cyanidation at Tonopah III," has just come to my notice and I am somewhat surprised to learn that the method of calculation of extraction referred to is in use in any of our "up-to-the-minute-in-efficiency" milling plants, and I am inclined to at once agree with Mr. Megraw that the question of such method should be discussed. The estimation of mill-head contents by adding bullion content to tailing content and dividing by tonnage, is not a method worthy of a metallurgist, and, as Mr. Megraw so fittingly puts it, is certainly "a method of solving a problem by means of which any answer is the right one."

Such methods are not, I believe, in general use, but are being mostly used by operators for stock companies. There are two classes of mining shareholders; those holding shares as an income-gaining investment, and those holding them for the purpose of speculation. Dividend-receiving shareholders do not exact highest efficiency. They are glad to get a dividend instead of an assessment and seldom question the methods. Those holding shares for stock operating are not interested. If the mine is paying its way, with an occasional dividend, declared at the right time to stimulate a dull market, nothing more is expected or wanted. However, from an engineer's standpoint, or from a business man's standpoint, the system leaves much to be desired.

Not only is the system referred to the source of inaccurate statements and fictitious results, but it is unscientific and unbusinesslike, and tends to show a lack of moral courage on the part of the well-paid specialists

in charge of operations. Advocates of the system will claim that they are continually watching results and working toward better extractions, and that they get everything possible out of the ore anyway, so why undertake additional work which would result in no benefit and only confuse the records. How do they know they are getting everything possible out of the ore, if they do not know what the ore contains to start with? They tell by the tailing assays; if these are low they assume results to be correct. How do they know that the bullion recovered is the true difference between head and tail content? Tailing content may be low and still the bullion produced may not represent what should have been recovered from the ore, or perhaps what really was extracted. Losses may occur through carelessness, faulty treatment, or dishonesty. These losses, which may amount to much, are entirely unguarded under such a system.

If an operator is afraid of his mill head, why is he not afraid of his mill tailing? He probably is not afraid of either alone, but does not care to meet both together, particularly when he is standing between them with the "brick." There is no reason why the tailing sample or assay should be more reliable than the head sample or assay. In many cases, it is much less reliable. Who ever heard of a correct tailing sample during the time anything was going wrong in the mill, especially when there was no record of heads? How can tonnage represented by tailing samples be as accurately established as tonnage represented by head samples? In cases where sand and slime are treated separately, the calculation of proportionate tonnage increases such inaccuracy.

When the head content is known, an efficient system of solution sampling will check both bullion and tailing, but when the head is unknown, this will only check the bullion. It is true that bullion plus tailing content is equal to the head content if no losses or errors occur, but they do occur, and hence the formula instead of being $B + T = H$, should be written $B + T + L = H$. But H and L being both unknown quantities, "any answer is the right one."

By having the head assay, precipitation record from solution assays, tailing assays and correct tonnage record, results are positive and any discrepancy represents loss or error, the two most important things the metallurgist is paid to guard against. He is not necessarily careless or incompetent when such discrepancies occur, but displays his ability when he finds and removes the causes for such losses or errors. Having no head assay, it requires no ability on the part of the metallurgist to keep his records free from discrepancies except that he must be able to add correctly.

By one method the treatment is controlled or regulated by a knowledge, before treatment, of what is being treated. By the other method

the treatment is controlled or regulated by a knowledge, after treatment, of what was treated. By one method the operator is able to arrange his treatment so as to secure the best results, by the other he makes a guess and then, after treatment is finished, he determines how far he was off and makes his answer right by fitting his original problem to it. He never does know what per cent. extraction is being made (a \$2 tailing may be the result of better per cent. extraction than a \$1 tailing), not that it makes any material difference, as the actual amount of bullion is the main thing, but he reports his percentages just the same; how?

The method is also unfair to the mine. The mill keeps its record clean and all contained values that come to it are accounted for and reported either in bullion or tailing, but the mine must stand its own losses as well as those of the mill. The mine may be sending \$20 ore to the mill, but the $B + T$ system may only show \$18 as mill head, which is all the mill will acknowledge receiving. What becomes of the \$2? Where is it charged? Who loses it? It flutters about unaccounted for, for a time, and then finally settles, unknown and unnoticed in the little nest of "shrinkage of previously estimated ore reserves," shown in no report, a most convenient hiding place for inaccuracies, losses and results of the inefficient method of "calculation of extractions." If a careful investigation were made into the cause of discrepancies in mill results, on account of which this "any-answer is the right one" method has been adopted, it will be found that an incorrect tonnage record is a greater factor in the matter than will be generally conceded.

A. SIDNEY ADDITON.

San Francisco, Calif., June 14, 1913.

The custom of using the content of bullion produced plus the content of tailing discharged as the value of the feed in milling operations, as stated by Mr. McGraw in the *JOURNAL* of Mar. 8, 1913, easily accounts for the high percentages of extraction frequently reported. Occasionally more reasonable estimates¹ may be found in the reports published by

$A - B$	When
$\times 100 C$	A Assay value of feed;
$C - B$	B Assay value of tailings;
$\div A$	C Assay value of concentrates.
	% extraction.

This formula would give correct results if the assays of feed and tailings could be relied upon, but with an assay of settled tailings, i. e., tailings minus float, the extraction percentages so obtained may be more than 18% above the actual extraction and

¹A formula much used for calculating the extraction, and which is stated to be convenient for approximate estimations when it is impracticable to weigh the products, is the following:

it is therefore undesirable to make use of this formula. Ashcroft "The Flotation Process," "Trans.," I. M. M., 1912, and "Eng. and Min. Journ.," Dec. 7, 1912, p. 1085.

large mining companies working low-grade ores, as such companies generally make use of sampling devices and employ their own assayers, but no calculation into which the assay value of the tailing enters can be of value because, under working conditions, it is impossible to ascertain directly the real value of the tailing.

From the moment concentration commences the water made use of carries off mineral of value, and this continues all through the process. The amount of floating mineral will vary with the fineness of division of the particles, degree of concentration, amount of water used, and inclination of the tables, or with the rapidity of concentration. The effect of these circumstances is to cause the settled tailing to be invariably of lower assay value than if there were no float.

The subject of extraction percentages is one which occupied my attention for several years, owing to my having been engaged by a mining company to carry out investigations with a view to ascertaining the amount and manner of loss in the wet concentration of silver ores. No trouble or expense was to be spared and ample opportunity was afforded to make experiments on whatever scale seemed advisable.

To estimate the extraction it was clearly necessary to know either the correct value of the mill feed or of the tailing. To obtain the tailing value was difficult on account of the constant loss in the overflow and the impossibility of collecting the whole of the material under ordinary circumstances of working, and it was therefore decided to depend on the assay value of the feed.

During the tests, samples of the settled tailing were taken and assayed, but in no instance did their value agree with the theoretical value obtained by difference. Their value was invariably lower and the difference greater with higher degrees of concentration. At first, it was supposed that some error had been made in sampling or assaying, and check samples were taken and assayed, but these only confirmed the low value of the settled tailing. In the opinion of the operators, the water only carried off the more soluble portion of the waste. It seemed, however, that the mineral accompanying this might account for the low value of the settled tailing. After this, a number of tests were made to ascertain the extraction in jigging, in sand treatment, and in concentrating slime, by concentrating in the usual manner about 10 tons of ore in the same condition as fed to the different machines, it being possible in concentrating a moderate quantity of ore to collect the entire tailing in tanks. As a result of many tests it appeared that the percentage of floating material was proportional to the fineness of the particles treated

and that its value was more than twice the theoretical assay value of the tailing. Thus, the discrepancy between the theoretical and actual assay value of settled tailing was accounted for.

The tests referred to were made with the same care in weighing, sampling and assaying the ore and products of concentration as would be exercised by a smelter purchasing ore, and were under my constant personal inspection, the object being to arrive at the actual rate of loss per degree of concentration of value in each of the three operations mentioned. The assumption was that with this data it would be possible to calculate with precision the probable results to be obtained in concentrating ores of different assay value to different degrees of value, by the methods of concentration made use of at the establishment under consideration, without the necessity of weighing the feed or the tailing.

Loss in concentration appears to arise from: First, the unavoidable loss characteristic of the particular ore concentrated, arising from the degree of natural concentration of the value in the gangue, its combination with various sulphides, and the nature of these; and second, the degree of division of the particles, which is the main cause of loss.

Some minerals are more friable than others, but the percentage of mineral to gangue is so small that it would not materially affect the general friability of the mass, and it may be assumed that ore of different minerals will crush in a similar manner and that the effect of division would be similar, although the float slime might be of higher value with friable ore. Hence, the weight of float arising from a certain degree of crushing an ore may be taken to be a measure of the percentage of float in crushing any ore to a similar degree, and this appears to be confirmed by the few examples which it has been possible to obtain.

The accompanying scale of extraction percentages obtained in concentrating a silver ore, crushed to pass a 30-mesh screen, aperture 0.0166 in., will illustrate the application of the results of some of the tests made. The silver was associated mainly with iron pyrites and a small amount of blende and occasional small quantities of galena, and occurred as pyrargyrite and in combination with copper (fahlerz). The matrix was quartz of average hardness.

The extraction by formula based on the assay value of the settled tailing was 4.2669% at 2:1 concentration, and 18.3545% at 12:1 concentration, in excess of the actual extraction.

It will be observed that the difference in the assay value of the settled tailing and the total tailing is so small in low degrees of concentration that, with ores of little value, it might escape attention unless great care were taken in sampling and assaying.

The method adopted for finding the percentages of extraction and loss incurred, weight and value of concentrates and tailings, for any

The total possible loss being 100%, the loss due to different degrees of concentration of the values will be proportionate percentages of this loss according to the degree of concentration:

PERCENTAGE OF LOSS IN VARIOUS DEGREES OF CONCENTRATION

Degree = % of total loss

0=0
2=50.0
3=62.5
4=75.
5=78.125
6=81.25
7=84.375
8=87.5

Degree = % of total loss

9=88.28
10=89.06
11=89.84
12=90.625
13=91.41
14=92.19
15=92.97
16=93.75

To find the total loss, first divide the assay of the concentrate by the assay of the feed to find the degree of concentration, then by means of the table find the relative percentage and, from this, the total loss. When the total loss is found by means of a test, the loss in concentrating similar ore of any assay value, and in a similar state of division, may be found, as it will correspond to the percentage of the total loss for that degree. In this manner the percentage weight of tailing and concentrate may be found and the actual value of the tailing.

The total loss may exceed 100% when the rate of loss is great, due to water used in concentration being excessive—or there is a reversal of concentration.

A knowledge of what the actual value of the tailing may be at different degrees of concentration is of great importance, as concentration may be carried to such an extent as to become negative, that is to say, the discard will be of greater value than the feed, owing to the tailing increasing in value in proportion to the degree of concentration. The first tailing discarded, up to a concentration of 2 : 1, is the largest in amount and the least valuable. After this it becomes richer and less in quantity; this, however, is liable to pass unnoticed, as the amount being small in comparison with the first tailing, the average value of the whole of the tailing is not greatly increased. The following example of concentrating copper ore, sand and slime, with bubbles will illustrate this:

Degree of concentration	Tons concentrate %	Tons tailing %	Extraction %	Loss %	Average value of tailing units
2	22.56	77.44	45.12	54.88	7.0868
4	4.42	95.58	17.68	82.32	8.6127
8	0.495	99.505	3.96	96.04	9.6518

The unit has been taken as 10 for feed.

In this scale of concentration the total loss found by experiment was 109.76%, so that there was a reversal of concentration at some point. Concentrating 22.56 tons to 4:1 would produce 4.42 tons concentrate with 18.14 tons tailing at 15.127 units, but concentrating to 2.5 deg. the tailing would be worth 9.463 units, the limit to which concentration could be carried without reversal.

In the vanner treatment, the total possible loss, found by experiment was 106.66, about the same as with the buddles; consequently it was not possible to concentrate beyond 2.5 degrees in either case. The concentration, however, was carried to 4.9471 degrees by vanners and 2.6277 degrees by buddles. The combined concentration was, by jigs, 12.734 degrees, extraction, 57.095%; by vanners, 4.9471 degrees, extraction, 17.589%; and by buddles, 2.6277 degrees, extraction, 36.545%; and combined, 8.4692 degrees, extraction, 69.575%. Assuming the data given to be correct, the tailing would have an average content per ton, 0.70443% copper, of which, according to the loss in float resulting in tests of silver ores, 35% of the weight of tailing would have been carried off with 57% of the calculated contents of same, and the value of the settled tailing would have become reduced to 0.46594% copper, equal to a reduction of 0.23849% in the percentage value.

Calculating the percentage of extraction by the formula, with value of settled tailing 0.4659%, an extraction of 80.10% would be obtained or 15.127% in excess of the actual combined extraction. The excess, however, would be much more in calculating separate recoveries by vanners or buddles.

The relative extraction by the different machines at the same degree of concentration was: Jig, 76.48%; vanner, 46.67; buddle, 45.12%. This must not be considered as a measure of efficiency but, if anything, a measure of the fineness of division of the particles. The float percentage on the tailing was: Jig, 10 to 15%; sand tables, 30%, due to a portion being reground; buddles, 45%, due to nearly all being reground.

A single test was not found to be sufficient as a test of the recovery or of the amount of float occurring in the operations of a mill, because, in working, buddle heads are sent to tables, and table seconds and slime go to buddles, and these combinations alter the conditions. It was found that the regrinding greatly increased the loss and this without doubt was the main cause of lower results being obtained under working conditions than in single tests. The main loss arises from float whatever machine is used and there appears to be little chance of overcoming this difficulty. The great loss of tin slimes in Cornwall is evidence of this—but it may be possible to improve extraction by paying more attention to coarser crushing and jigging. It is not sufficient to infer from observation only that an ore requires to be crushed fine to obtain the best results

in its concentration and the possibility of obtaining better results from coarse crushing may well repay the trouble of carefully ascertaining the most favorable degree of crushing in each case, as even adjacent veins vary much in the natural concentration of their values. With silver ores, the tailing is hardly ever of lower value than 8s. per ton; consequently, every ton of waste picked out by hand before concentration results in a considerable saving, as it raises the value of the remainder, thereby reducing the degree of concentration required and, at the same time, reducing the loss in treatment of the whole.

WILLIAM S. WELTON.

London, Eng., Apr. 8, 1913.

CHAPTER XIII

THE NEVADA HILLS MILL, AT FAIRVIEW

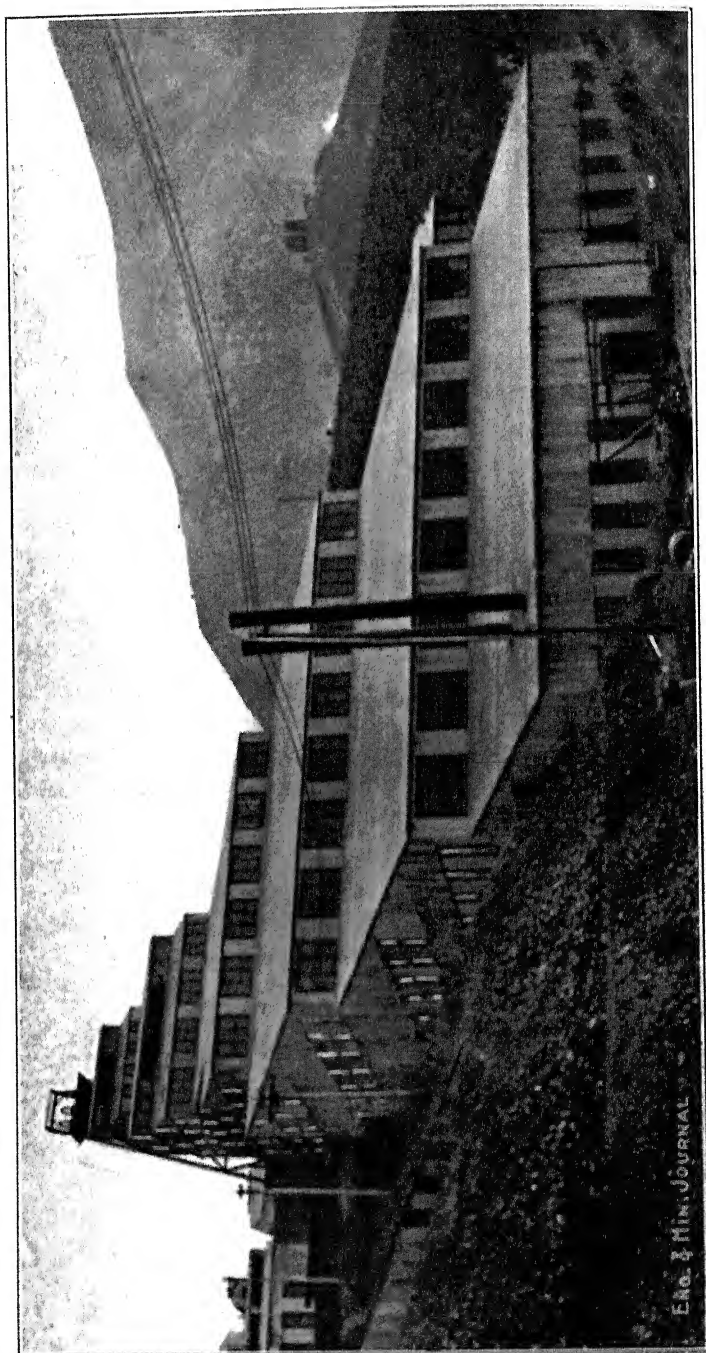
The plant of the Nevada Hills Mining Co. is situated at Fairview, about 45 miles southeast of Fallon, Nev., the nearest railroad station. Due to the lack of immediate railroad communication the entry of supplies is slow and somewhat expensive. A line of automobile stages, however, makes passenger and mail transportation more easy and simple. The situation of the plant, so far removed from the railroad point, makes the obtaining and retaining of competent labor somewhat difficult. The fact that the company is the only one operating actively in the district does not help matters in this respect, and it is stated that the labor question is one of the important ones to be handled.

Varied Character of the Ores.—The ores milled at the Nevada Hills mill vary in both character and hardness, but on the average may be said to be somewhat harder than the usual Nevada silver ores. In character they vary from clean, easily treated mineral to complex deposits, which give some trouble in beneficiation. The oxidized ores contain a certain quantity of manganese and are generally more difficult to cyanide than the sulphides, an extraction of 87% being usual on the former and on the latter 94% or more. Calculating on a basis of the average mill run an extraction of 92% is obtained. The mill treats from 120 to 140 tons per day, depending on the character of the rock. The proportion of silver is about as 100 : 1, the ordinary mill heads averaging \$20 to \$22 per ton.

The mill is situated at the shaft head, thus obviating transportation difficulties, the mine skips dumping directly into a bin at the head of the mill. The mill building is a steel-frame structure covered with iron, substantial and well built.

Sampling and Weighing Plant.—The ore coming from the mine is dumped into a 300-ton bin from which it is fed to a Blake crusher, the product of which passes over a shaking grizzly into an elevator. This elevator lifts the rock to a sorting and conveying belt, where the waste is taken out after the whole has been given a spraying wash, to facilitate the sorting operation.

The original design of the mill included at this point an automatic weighing device and sampling plant, but both of these have now been eliminated from the operating plan and the passage of ore is as above



NEVADA HILLS MILL, FAIRVIEW, NEV.

stated. The reasoning leading to the abandonment of these steps is that the expense of operating them was more than any advantages gained from them. It is noteworthy that practically the same condition obtains at the mill of the Goldfield Consolidated, at Goldfield, where the extensive sampling plant originally built was never replaced after its destruction by fire.

Whether a sampling and weighing plant is worth its cost of installation is a question which seems to have been decided in the negative in recent years, although in former times such refinements were considered indications of approximate perfection. The system of calculating extraction percentages by using the sum of bullion output plus tailing content as the content of ore entering the mill has rendered sampling unnecessary and weights can be approximated in some other more economical manner than by actually passing the mill run over scales. In speaking of the Tonopah mills I have already referred to this method and in writing on conditions at the Black Hills I mentioned the advisability of sampling and weighing plants for these mills. These later facts brought out by the investigation of further plants will modify the conclusions made earlier, but even at this time I do not feel altogether convinced that the methods so universally used at the present time are the best ones.

Methods of Calculating Extractions.—The arguments used by adherents of the latest method of calculating extractions are that even with elaborate sampling plants it is difficult to obtain an accurate sample; that even if accurate samples are secured, they are liable to corruption through the inaccuracies of assaying, the fact being advanced that there is always a certain loss in assays and that the loss on the higher-grade samples, heads, is greater than on the lower-grade samples, tailing; and that the varying amount of metal contained in mill pulp and solutions makes accurate calculation an impossibility in any case. All these arguments, no doubt, have weight, although it does seem that some method of calculating a check could be devised.

As concerns sampling and weighing, I am convinced that by using properly designed apparatus in the hands of competent operators an accurate sample is possible. And also that chemical science is not so limited but that an exact estimation of the contained metal in any sample can be made. As to the conditions within the mills themselves, that is an entirely different matter and a question not so easily solved. In the older style of mill where sand and slime are treated separately, the slime going through the mill in three or four days while the sand portion remains in process of treatment as much as 15 days, it is evidently impossible to calculate extractions over a short period of time, although if the period be long enough a fair approximation of accuracy should be obtainable. In the newer mills treating all the ore as one product, calculations ought

to be considerably simplified. In its present condition this question can hardly be considered definitely settled and I believe operators ought to discuss it publicly and see if some satisfactory solution cannot be advanced.

Chemical Consumption and Operating Cost.—The consumption of material is about as follows: Cyanide, 2.7 lb.; lime, 9 lb.; lead acetate, 0.8 lb.; zinc, 1.5 lb. per ton; pebbles, 3 lb. per ton of ore milled. The cost of operation at the Nevada Hills mill is given completely in the accompanying table:

OPERATING COSTS AT NEVADA HILLS MILL

		Per ton ore milled
Crushing:		
Labor.....	\$0.052	
Repairs.....	0.003	
Power.....	0.016	\$0.071
Stamping:		
Labor.....	0.106	
Repairs.....	0.024	
Power.....	0.117	0.247
Concentrating:		
Labor.....	0.087	
Material.....	0.011	
Power.....	0.021	0.119
Elevating and separating:		
Labor.....	0.042	
Material.....	0.004	
Power.....	0.025	0.071
Assaying and sampling:		
Labor.....	0.134	
Material.....	0.001	
Power.....	0.008	0.143
Tube milling:		
Labor.....	0.040	
Material.....	0.104	
Power.....	0.149	0.293
Settling and agitating:		
Labor.....	0.105	
Material.....	0.655	
Power.....	0.062	0.822
Continuous decantation:		
Labor.....	0.020	
Material.....	0.004	
Power.....	0.008	0.032
Filtering:		
Labor.....	0.096	
Material.....	0.028	
Power.....	0.052	0.176

OPERATING COSTS AT NEVADA HILLS MILL—(Continued)

		Per ton ore milled
Discharging:		
Labor.....	0.066	
Material.....	0.046	
Power.....	0.013	0.125
Precipitation:		
Labor.....	0.057	
Material.....	0.191	
Power.....	0.032	0.280
Refining:		
Labor.....	0.073	
Material.....	0.077	
Power.....	0.003	0.153
Heating:		
Labor.....	0.004	
Fuel (oil).....	0.052	0.056
Water.....		0.005
Surface equipment:		
Labor.....	0.007	
Material.....	0.003	
Power.....	0.004	0.014
General expense:		
Labor.....	0.015	0.015
Total.....		<u>\$2.622</u>
Note—Cost based on milling 4030 tons of ore in 30 days.		

The ore ready for the mill is dumped into a 600-ton mill bin back of the batteries, into which it is fed through feeders of the Challenge type, but driving by means of a wire rope instead of the usual grip used on them.

There are 20 stamps, each 1250 lb. in weight, making 107 drops through 6½ in. and crushing through 8-mesh screen. The pulp from the stamps is delivered into two cone classifiers, each 36 in. diameter, where it is divided into two portions, one containing the coarser sand and the other the finer part of the pulp.

Classified Concentration.—The underflow, or sandy portion, from the classifiers is passed to a pulp distributor, whence it is distributed to six No. 2 Deister concentrators, the overflow of the cone passing around this concentration system into a second battery of two hydraulic cone classifiers.

The tailing from the sand concentrators is passed to Akins classifiers. The overflow from the first classifiers passes to the second battery, where the underflow, containing the heavier part of the pulp, goes to another pulp distributor and thence to eight No. 3 Deister concentrators. The

overflow, consisting of slime ready for agitation treatment, goes directly to the first thickener, as will be mentioned.

From the slime concentrators, the pulp with the concentrate removed, flows to a distributor which divides it in two and delivers to two 48-in. Akins classifiers, these being of the well-known interrupted spiral flight type, the overflowing slime joining that coming from the second battery of hydraulic classifiers, while the sand is passed to another distributor which delivers to two tube mills, each 5 × 18 ft. The reground product from these mills is returned to the second battery of classifiers, where the slimed portion is taken out and the remaining pulp follows through the concentration and mechanical classification process. This procedure is shown in the accompanying flow sheet.

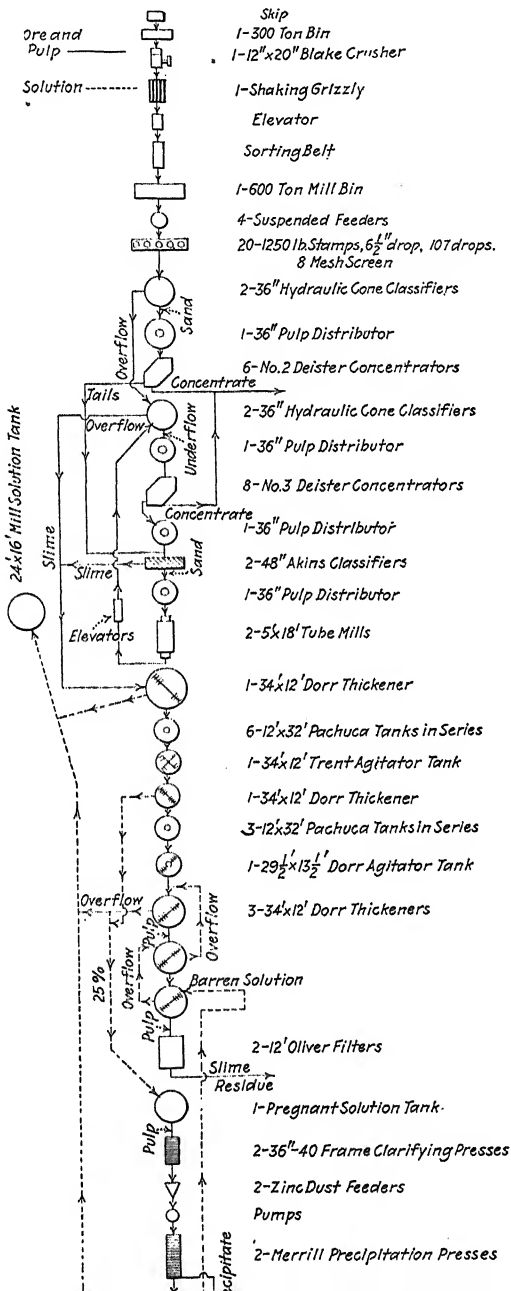
Continuous Agitation. The slime for agitation is taken first to one Dorr thickener, 34 × 12 ft., where it is thickened from about 6:1 to 1:1. Issuing from this thickener, the pulp goes to the agitation series, before reaching which, however, it is diluted to 2 or 2½:1 by solution made up to treatment strength, which contains 5 lb. KCN per ton. The solution used throughout the mill averages 3 lb. per ton, all crushing being in solution.

There are nine agitation tanks of the Pachuca type, each 12 ft. diameter by 32 ft. deep. The pulp for treatment passes through six of these tanks in series, the flow being continuous. From these tanks it is taken to a Trent agitator tank, of the same size as the thickener, and thence to a 34 × 12-ft. Dorr thickener. Here the pulp is thickened again to about 1:1, and subsequently diluted with fresh made up solution. The pulp then passes to another series consisting of three Pachuca tanks, of the same size as those formerly mentioned, through which it passes continuously.

This interrupted agitation series is especially worthy of note, as it accomplishes a continuous agitation and also a change of solution, a condition making for better extraction and one which I advocated some years ago for silver ores when continuous agitation was proposed but not generally practised.¹ The advantage of a change of solution during a long agitation period is generally recognized and this method of accomplishing it can hardly fail to produce beneficial results.

Washing by Decantation. From the second agitation series the pulp is passed to a tank 29.5 ft. diameter by 13.5 ft. deep, in which is installed a Dorr agitating mechanism. In passing it is worth while to mention the working of this machine. It has two agitating arms which revolve at 4½ r.p.m., and the central air-lift pipe is 12 in. diameter. This air lift delivers the pulp to two arms suspended above the surface of the pulp in the tank and which revolve in unison with the submerged arms. The

¹ "Continuous Processes," Mex. Min. Journ., August, 1910.



outside arms consist of a launder which carries the pulp from the air lift and drops it at various points over the tank surface, an arrangement of slots or openings allowing an equal distribution. It is stated that tests have shown that the pulp within this agitator maintains its homogeneity at all points within 2% when tested by specific gravity, pulp assay or screen test.

From this agitator the pulp passes to three Dorr thickeners, operated as a continuous-decantation system. The flow sheet illustrates the operation of this series which, it will be noticed, takes in barren solution at the final thickener and passes it back through successive tanks until it overflows at the first one, enriching itself and impoverishing the pulp. This is an exemplification of the proper working of the counter-current decantation method, of which I have already spoken. By its use an effective washing of the solids is accomplished and also a lightening of the burden upon the filtering machine.

From the final thickener of the series the pulp is taken to two 12-ft. Oliver filters where final dewatering is done. A water wash is applied to the ascending side of the filter, but, none on the descend-side, as economy of water is necessary and by this means the discharged pulp contains a minimum of moisture. The slime is discharged upon a conveyor belt, by which it is carried clear of the mill and deposited on the tailing pile. It contains an average of 27% moisture. At this mill, in distinction to the experience of the Tonopah mills, no advantage is found from heating the solutions above normal.

The solution to be precipitated is passed through clarifying presses and zinc dust is used to precipitate the metals. The precipitate is partially dried, fluxed and melted in oil-fired furnaces.

The lime used in treatment is added as an emulsion at the slime collector, the quantity being about 10 lb. per ton of ore milled.

CHAPTER XIV

PRACTICE AT THE NEVADA WONDER MILL

The mine and plant of the Nevada Wonder Mining Co. is situated at Wonder, Nev., at a distance of about 63 miles from Fallon, which is its nearest railroad station. Communication is by means of wagons for freight, and automobile stage for passengers and mail. As has already been mentioned in the case of the Nevada Hills company at Fairview, the isolated situation is responsible for high transportation charges and some measure of labor difficulties, the same condition applying at Wonder as at Fairview, but with somewhat more force due to the greater distance from communication.

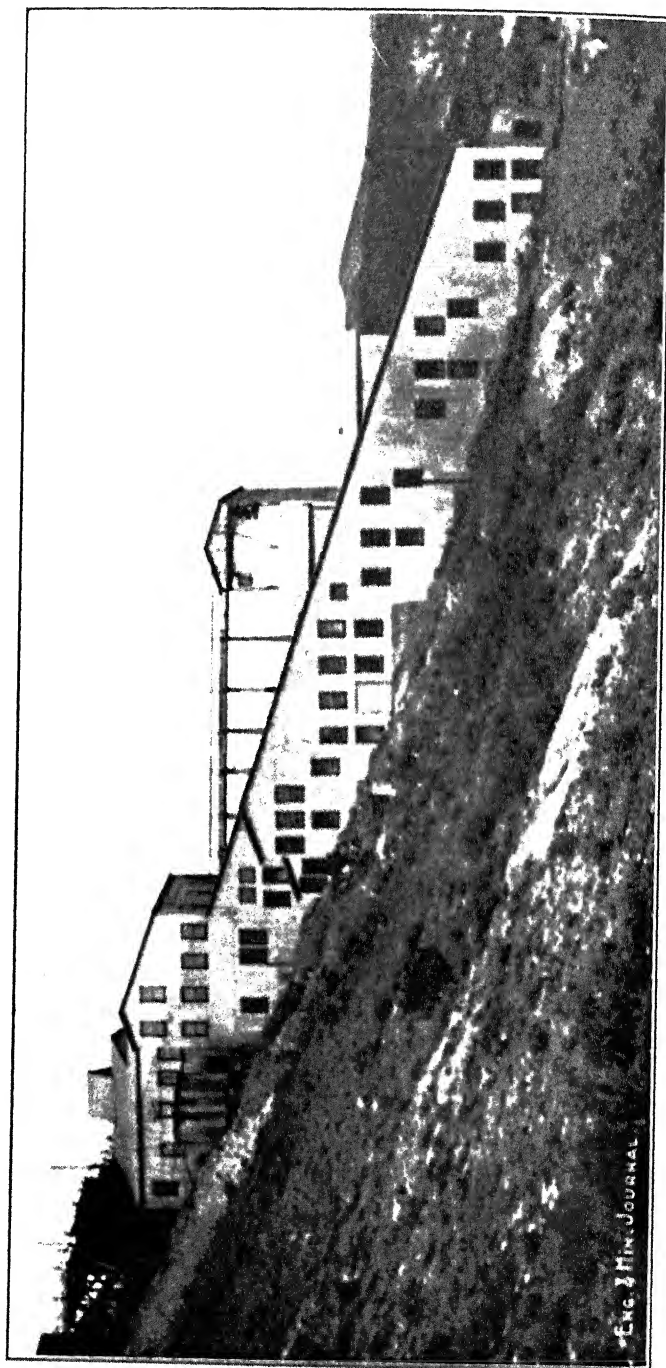
The ores treated at Wonder are clear quartz of medium hardness and offer no special difficulties in crushing. The plant treats an average of about 110 tons per day of 24 hours, the mill run assaying about 18 oz. silver and 0.25 oz. gold.

For convenience the property is operated by two companies, the mining being carried on by the Nevada Wonder Mining Co. and the milling by the Churchill Milling Company.

In its present condition the mill embodies a great many changes from its original treatment plan, some of these changes having necessitated ingenuity in installing additional apparatus in space which was not designed to receive it. Such changes often force awkward arrangements, but in this mill most of them have been planned and instituted without mechanically embarrassing results.

Crushing Practice.—The ore from the mine, after being weighed, is passed through a 10×16-in. Blake rock crusher which delivers to an inclined belt conveyor, the latter delivering into the battery bin. The battery bin is of 2550 cu.ft. capacity and holds about 120 tons of ore.

From the bin the ore moves by gravity through gates into suspended Challenge feeders delivering into the mortars. It is noted by the operators that the one-stage crushing through a Blake-type breaker throws a somewhat heavy burden upon the stamps. The crusher allows a proportion of large pieces of rock to get through into the battery bins and these may at times cause difficulty in the mortars. Probably a better course is to crush in two stages, insuring a uniform feed of proper size for stamp crushing.



NEVADA WONDER MILL, WONDER, NEV.

through 8 in. The mortars are of the narrow, rapid-crushing type and are equipped with screens of the square-mesh variety having an aperture of $\frac{3}{8}$ in. These stamps are relied upon in this instance to bear the heavy work of reduction, and the pulp from them is passed to one Monadnock chilean mill for the second stage. This mill makes 28 r.p.m. and is fitted with "ton-cap" screens having an aperture 0.08 in. wide.

Comparison of Time Loss with Stamps and Chilean Mills.—It is worth while at this point to consider the relative time lost on account of repairs to batteries and the chilean mill. One of the strong points made by objectors to chilean mills is the time required to make repairs to them, the claim being that stamps keep on working all the time without any great loss due to renewals and repairs. A great many operators fail to take into consideration the fact that while the stamps seem to be working steadily and making a great deal of noise about it, it is rare in a mill containing any great number of them that there is not one or more hung up for adjustment, setting tappets, putting on a dropped shoe, aligning, or doing any one of a number of operations that are necessary with that class of machinery. When a small proportion of stamps are hung up it does not make any apparent difference in operations, for the mill is making just about as much noise as if they were all running, but it must be considered that each individual stamp is relied upon to crush a certain definite number of tons of ore in a year and every hour one stamp is out of commission has its effect upon the total product. On the contrary, if a chilean mill is stopped for repair the whole work is hung up, there is no noise and it seems necessary to make every effort to get it running again. The effect is to make it appear that the chilean is taking much more time for repairs than the stamps, whereas, if all the minor delays of stamps are added up they will usually approximate as much or more than those made necessary by the chilean mill. As an instance, at the Wonder mill during a period of a year the time lost for battery repairs amounted to 7.70 days and the chilean mill, 3.66 days. There is a 100% difference in favor of the chilean mill. And in this case it is to be remembered that the feed delivered to the chilean is too fine to insure maximum efficiency or economy of wearing parts. Personal experience has been that the chilean requires a percentage of coarser feed to do its best work and I believe most operators agree with that theory today.

Tube-mill Grinding.—From the chilean mill the pulp passes to a duplex Dorr classifier where the already slimed portion is taken out and the sand passed to a tube mill. This mill is 5×22 ft. and makes 28 r.p.m. It will be noted that this mill is of the long type, due to the fact that it was installed before the advantages of shorter tubes of the same diameter were recognized. The mill contains a lining of the El Oro type, one of the very few of these linings I have seen in use in the West.

Classification of the tube-mill product is somewhat involved and is an illustration of one of the changes made in the original mill design already mentioned. The stream from the mill is split into two parts, each going to a separate belt elevator, one of which sends its portion directly back to the Dorr classifier and the other delivering to a 5-ft. classifying cone. The underflow of this cone is returned to tube-mill feed and the overflow is taken to a 7-ft. classifying cone which takes out the coarser part as underflow and returns it to the elevator leading back to the Dorr classifier, and passes its overflow, slime, directly to the slime collector. The accompanying flow sheet shows the movement of the pulp and solution.

Continuous Agitation System.—Slime is collected in a Dorr thickener, 24×14 ft., and the overflow solution passes to the precipitation department or to the battery tank. The thickened pulp is agitated intermittently in four Pachuca tanks, each 15×45 ft. The pulp receives about 40

COST OF MILLING AT WONDER, NEVADA

(Tons milled, 25,186—Period of one year.)

	Labor	Supplies	Power	Total
Superintendence.....	\$3,686.65	.....	.....	\$3,686.65
Crushing and conveying.....	1,651.14	618.51	800.40	3,070.05
Stamps.....	3,173.41	1,577.98	2,658.55	7,409.94
Chilean mill.....	1,435.97	2,014.96	1,722.62	5,173.55
Tube mill.....	1,017.58	2,126.37	2,213.44	5,357.39
Elevating and separating.....	945.01	566.84	476.65	1,988.50
Agitating.....	6,722.84	15,775.08	1,660.12	24,158.04
Filtering.....	2,679.01	953.25	1,161.52	4,793.78
Precipitating.....	987.27	7,044.47	.....	8,031.74
Refinery.....	3,048.98	5,736.84	154.58	8,940.40
Concentrating.....	543.63	88.87	.....	632.50
Assaying.....	1,086.10	1,120.53	41.92	2,248.55
Surface and plant ¹	2,101.77	503.97	521.19	3,126.93
General.....	374.11	508.91	.....	883.02
Storehouse.....	677.59	383.42	39.89	1,100.90
Water and fire line.....	719.54	617.79	.....	1,337.33
Steam heat.....	1,721.62	5,293.14	.....	7,014.76
Traction engine.....	139.68	32.13	.....	171.81
Total direct.....	32,711.90	44,963.06	11,450.87	89,125.84
Indirect				
Office expense.....	1,371.48	822.39	.....	2,193.87
Company house.....	86.06	105.48	.....	191.54
Taxes and insurance.....	.....	.....	.....	2,933.61
Legal and traveling.....	.....	.....	.....	267.54
Total indirect.....	1,547.54	927.87	.....	5,586.56
Direct cost per ton.....	.....	.....	.....	3.538
Indirect cost per ton.....	.....	.....	.....	0.222
Total cost per ton.....	.....	.....	.....	3.760

¹ Refers to building repairs, outside lighting, removal of debris, etc.

hours' agitation in these tanks and the solution used is heated to about 80°. Solution used for treatment contains 4.5 lb. KCN and 4 lb. lime per ton. Due to the fact that the ore is clean and docile, high extractions are the rule, the average over the past year being 94.49% of the gold and 94.74 of the silver. This percentage of recovery is good, especially so on the silver, due to the raising of the temperature of the solutions. It has been proved in this mill that the extraction falls off approximately 2% when the solution temperature is allowed to fall to or below 50° F. during treatment.

Continuous Filtration.—Pulp from the Pachuca agitation tanks is delivered to a stock tank, 28×14 ft., which is equipped with a mechanical agitator, and is diluted by the addition of 2 ft. of barren solution, and from this tank it is taken to a Dorr thickener. The overflow of this thickener goes to the precipitation department and the underflow of thickened slime is returned to the stock tank again. By this means the pulp is given a light washing and the content of the stock tank is maintained at a proper thickness for filtering.

Oliver filters are used, and the pulp, having already received the preliminary washing mentioned, is filtered continuously, receiving a final wash at the filter. The wash water applied at the filter is led through hoses to a shaking pipe where it is sprayed on the cake in a constantly moving stream. By this means the delivery of the wash to any one point is avoided and a better distribution is accomplished. The discharge from the filter is said to contain about 50% moisture.

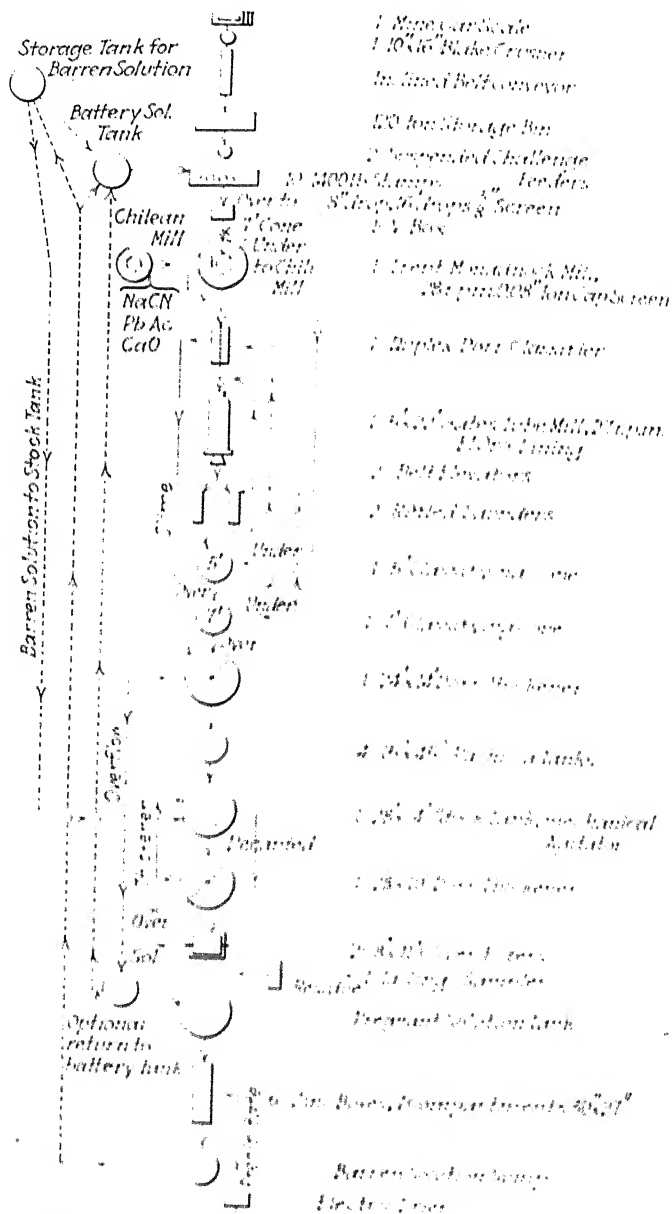
In this mill, as in many others, the centrifugal pump has proved a more economical and satisfactory method of moving slime pulp than the triplex slime pumps.

Solutions from the Dorr thickeners and from the filters are passed to the pregnant-solution tank from which the precipitation system is fed. There are six zinc boxes, each with seven compartments 30×27 in. area. Only five of these compartments are used for precipitation and the other two, at the heads of the boxes, are filled with excelsior and used for clarifying the solutions. Many of the Nevada mills are using excelsior for clarifying, as has already been mentioned in the case of the Tonopah mills, and it seems to do the work in a satisfactory manner.

The precipitate cleaned up is dried in a pan which is fitted with electrical means for heating, and is then fluxed and melted in Faber du Faur furnaces burning oil. In order to avoid the melting of short zinc which accumulates, an acid tank has been installed and this material finds its way into the regular bullion production.

Material Consumption and Cost.—Consumption of material at the Wonder mill is of cyanide, 1.6 lb. per ton of ore milled; of lime, 5½ lb.; of acetate, 0.8 lb.; of pebbles, 3 lb. and of zinc 1.8 lb. A feature of in-

DETAILS OF CYANIDE PRACTICE



terest is that the cyanide, lead acetate and lime required in treatment are all ground up together in a small chilean mill and added to the pulp flow between the chilean mill and the Dorr classifier. This is shown on the flow sheet.

The cost of milling is shown in the accompanying table, but it is to be remembered that the period of one year covered by these figures included 115 days lost due to lack of power and other less important causes, expenses naturally continuing to a large extent during that time. These expenses falling on the reduced tonnage show a cost abnormally high and it should be said that during the last two months when the mill was operating at its maximum rated capacity of approximately 110 tons per day, the expense dropped to about \$2.75 per ton.

Considering the situation of the mill and the difficulties under which the operators have been working, the results obtained are extremely creditable.

CHAPTER XV

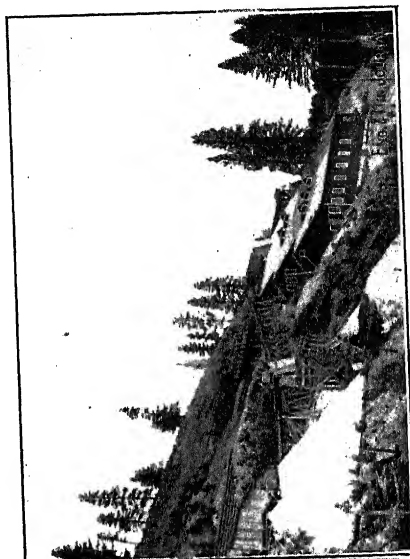
METHODS AT REPUBLIC, WASHINGTON

The mining camp of Republic is situated in the northwest section of Ferry County, Wash., about 25 miles south of the Canadian line. In common with most mining camps it has been the scene of intermittent activity and decline, and has had a hard time to demonstrate its value. The district, originally a part of the Colville Indian reservation, was opened in 1896 and its history since that time has been a checkered one of alternating interest and indifference. Lately, however, its mines have begun to be developed in a methodical manner which, if slow, is at least more satisfactory and certain than can be obtained by a succession of booms.

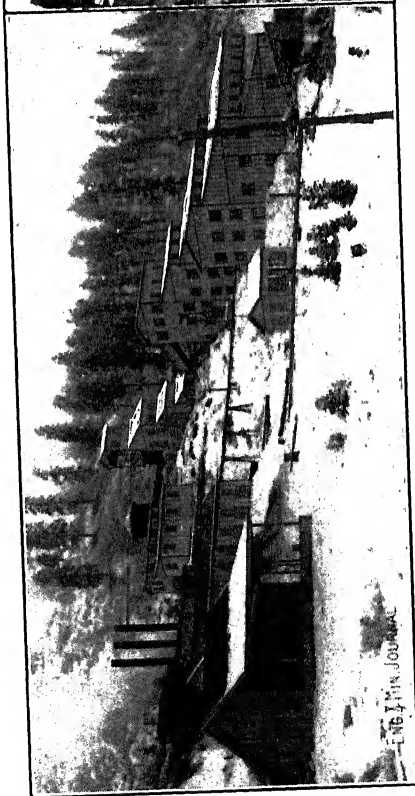
Metallurgical History of the Camp.—Republic has seen a series of mills built within her boundaries, none of which seems to have made any remarkable success. The first one was built for the Republic Gold Mining & Milling Co., and made use of the Pelatan-Clerici process. Naturally, this was not much of a success, the saving amounting to perhaps 50% of the contained silver and gold. Then followed a series of plants embodying the chlorination process, combined amalgamation and cyanide, the Hendryx cyanide system, and finally the plant constructed by D. C. Jackling for the Republic Power & Cyanide Co., built in 1900. This plant operated for about 10 months and was then shut down. It was patterned after the old Mercur plant in Utah, and included crushing by means of rolls and Griffin mills, roasting and leaching. Precipitation was attempted by the old method of using zinc dust in tanks, as was done at Mercur. This mill is reported to have saved about 91% of the gold in the ore but only about 15% of the silver.

Due to the many methods of treatment and the apparent failure of all of them to accomplish any commercially successful results, the camp received a bad name and the ores, while the quantity and grade were acknowledged, were thought impossible to treat by any means sufficiently cheap to insure profit. As a matter of fact, the trouble appears to have been the persistent attempts to fit a process which had proved useful somewhere else to the ores at hand, which happened to be not in the least appropriate for it.

There seems to have been a remarkable lot of misinformation published about the character of the ores. Some experimenters went to a



SAN POIL CONSOLIDATED MILL, REPUBLIC, WASH.



NORTH WASHINGTON POWER & REDUCTION CO.'S MILL.

great deal of trouble to prove that they were not treatable cheaply, and apparently satisfied themselves and a large portion of the mining public. That the mineral itself does not justify this conclusion, the two plants now in operation prove.

Description of the Ore.—The ore is described as being a fine grained, close textured quartz, but there is also some white quartz which is not so hard and which is easily distinguished from the blue, flinty, hard material mentioned. Ore from some portions of the camp is more like a clay and contains an extremely large amount of colloid matter. It will be seen that there is a great variety of ore, but that at present worked by the mills consists largely of the blue quartz and white quartz, and is, in general, hard.

While it has been repeatedly stated that this ore contains elements which make it rebellious to cyanide treatment, such as tellurium, selenium and copper, repeated tests have failed to detect tellurium, selenium exists only in minute traces in ores of milling grade, and copper only in small quantities. Neither of these last two elements presents any insuperable obstacle to cyanidation as selenium compounds are usually soluble and exist in quantities too small to consume excessive amounts of cyanide, and the same is true of copper, which occurs in somewhat larger quantities.

It is undoubtedly true that the ores did not prove amenable to the processes applied to them, but as has been stated, these methods were not adapted to the ores. Later methods and careful experimentation has, however, opened up an entirely new viewpoint.

In discussing the matter, H. W. Newton, superintendent of the mill of the North Washington Power & Reduction Co., at Republic, who is familiar with the ores, having studied them and experimented on them for years, and who is responsible for their present successful treatment, stated that he had made a number of experiments on roasted samples and invariably found that while a slight increase of gold extraction was obtained on subsequent cyanidation, invariably the extraction of silver decreased and almost disappeared. This was undoubtedly one of the reasons why the mill built by Jackling was not successful as the silver is in quantities too great to be ignored and constitutes a large proportion of the value.

Another point which has been detected and pointed out by Mr. Newton is that the gold occurs in such fine particles as to be rarely visible, is scattered through an extremely close-grained rock so that the finest grinding is necessary to liberate it and expose it to the action of cyanide solutions.

The silver probably occurs as a sulphide, or sub-sulphide, and is soluble readily enough in stronger cyanide solutions, though when roasted it is converted into some other form, probably metallic silver, which is not

readily soluble in cyanide solutions. The reasonable treatment, then, would appear to be sliming of the total ore and agitation in cyanide solutions without roasting or any other auxiliary treatment. And this has proved to be the case.

The Crushing System.—The mill of the North Washington Power & Reduction Co. was commenced in 1911 and has now been in operation¹ something more than seven months. It handles ore from the Surprise and Lone Pine mines, a rather hard run of ore. Railroad cars deliver the ore to the mill where it passes through a system of crushing and sampling as shown by the accompanying flow sheet.

From the first bin, the ore passes over a grizzly to a Blake crusher and then over another grizzly to a set of 16×22-in. rolls. From this set of rolls it is passed through a wire-screen trommel, the apertures of which are $\frac{1}{8} \times \frac{1}{2}$ in. The oversize is taken to a set of 14×30-in. rolls, after passing which it joins the undersize from the trommel and passes through the sampling plant to the mill bin.

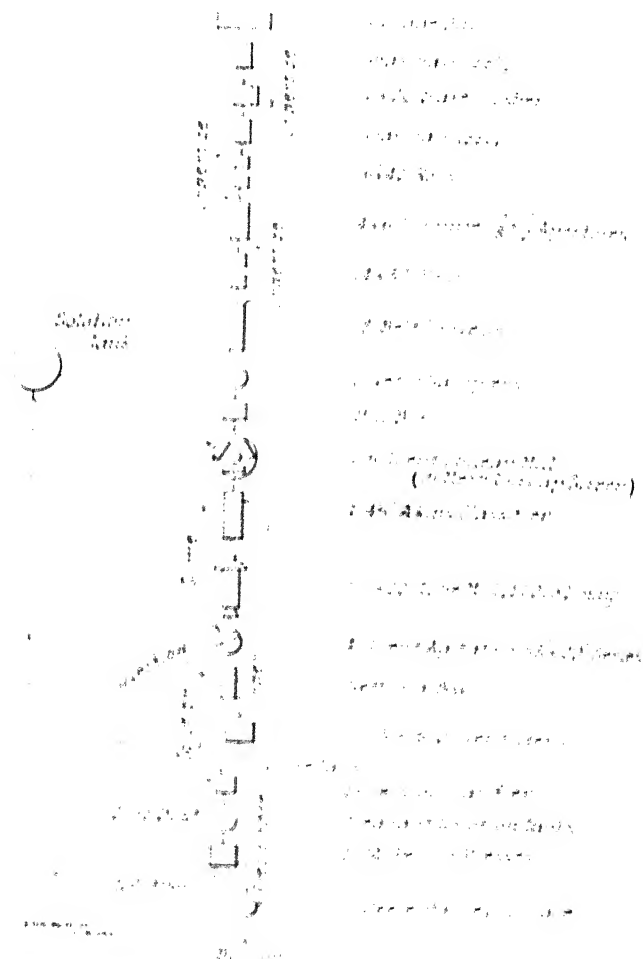
From the mill bin the ore, now reduced to such size that the largest pieces are about $\frac{3}{16}$ in., is passed to a chilean mill, where it is crushed to pass a 16-mesh screen, then through a 45-in. Akins classifier and the sand to a tube mill, 5×22 ft., where it is slimed.

There is some difficulty with this crushing system, the crucial point being in the chilean mill. The capacity of the plant is about 100 tons per day of 24 hr., and yet there is extreme difficulty in getting the chilean mill to crush the amount of coarse material contained in the feed, which is not large, through the 16-mesh screen. This condition should not exist, for the material is all small, as has been mentioned, and the screen is coarse. The difficulty probably depends on two factors, one of which is the fineness of the feed. A feed of this fineness is usually considered too small to give maximum efficiency with a chilean mill, although at some plants large capacities are obtained with similar material. This is exemplified at the Portland and Independence mills at Cripple Creek. Too fine feed in a chilean mill usually results in building a bed on the die ring, the rollers riding over it without doing much grinding, and the operators at the North Washington mill state that this is what occurs in this case, but they also state that increasing the size of the material decreases the capacity, and conversely, though with a very fine feed there is not much left for the mill to do but pulp the material and put it through the screen.

The probability is that there is something wrong with the design of this chilean mill and that it is not adapted to ores of this kind. I feel convinced that under normal conditions there would be no difficulty in handling a sufficient tonnage of this material. It is reduced with greatest ease in the rolls.

¹ At date of this article.

Tube-mill Practice. At present there is one tube mill in operation, as has been mentioned, but serious consideration is being given to the installation of a second one, and the replacement of the Chilean mill with a short tube mill of large diameter, having ribbed lining of the Komata type. This would probably be an advantageous change and by it the capacity of the mill could be materially increased. A short mill of large diameter



FLOW SHEET OF THE NORTH WASHINGTON POWER & REDUCTION CO.'S MILL.

equipped with the ribbed lining would efficiently break up the coarser portion of this mill-run of ore and leave a product sufficiently varied to be efficiently slimed in the succeeding two fine-grinding mills.

Closed circuit between the classifier and tube mill is effected and the slime which leaves the classifier is taken to the first of a series of f-

agitation tanks, 33×20 ft., which are equipped with the Trent agitator.

The operators claim that every satisfaction is obtained from the use of these agitators even in the large, deep tanks installed. They perform their work with a minimum of trouble and give good results in extraction. The aëration of the pulp is said to be good and extraction proceeds satisfactorily.

The first tank is used as a thickener as well as agitator, the overflow going to the precipitation department. Agitation is continuous through the series of tanks, the passage through them being accomplished in about 36 to 40 hours.

It will be noted that the agitation capacity of these tanks is sufficient for a good deal more tonnage than can be delivered by the crushing and grinding department. The slight changes necessary for increase of that part of the mill would be well worth making.

Use of Cyanide and Other Chemicals.—The strength of the cyanide solution in these agitation tanks is kept at about 5 lb. KCN per ton of solution. While a solution containing 2 lb. per ton would be ample for the extraction of the gold, in less time also, the strength is kept up to 5 lb. in order to make the best possible extraction of silver. The lime is added to the first of the series of agitation tanks at which point also the solution is standardized in cyanide content.

Lead acetate is used intermittently. It has been found that after several days' use of the acetate it can be discontinued for a long time, the relation being approximately, using it for one week and omitting it for three weeks. If it is discontinued for much more than this time, trouble develops which is believed to be due to soluble sulphides, the condition being immediately remedied by the addition of the lead salt.

From the agitation system the pulp is either taken directly to the Oliver filter or is first passed through a settling box for thickening it. The procedure is usually to omit the settling box as the pulp is already in good condition for filtering.

The Oliver filter is a large one, 11.5×16 ft., and is said to be doing excellent work.

Precipitation Details.—Zinc dust is used for precipitation, this being the most acceptable method when treating ores containing copper, as the metal is recovered immediately from the solution and does not tend to make useless a large amount of zinc, as is the case when shavings are used. The Bosqui system of agitating zinc dust in tanks with the pregnant solution and then pumping the mixture through a filter press, is followed.

There is not a large amount of copper present, but what little there is may be removed in this way from solution. A statement of the compara-

tive content of the ores milled is given as follows: From the Surprise mine, gold, 0.51 oz.; silver, 5.80 oz.; copper, 0.2%, and from the Lone Pine Mine, gold, 0.32 oz.; silver, 2.20 oz.; copper, 0.1%. It will be seen from this statement that the copper is not in sufficient quantity to cause any great difficulty.

The average grade of ore treated at the mill for six months has been \$9.55, and the extraction of gold during this time was 92.8% and of silver 90.5%. The consumption of cyanide is 1.3 lb. per ton of ore treated, of lime, 4.5 lb., and of Zn, 0.6 pound.

The mill consumes 2 hp. for each ton of ore milled and employs 12 men in its actual operation in addition to six men at the power plant. Power is electric, generated by a not very efficient steam plant at the mill and is expensive. It is expected that hydroelectric power will be available within the near future when, based on the expenses at the present time, the total cost of treating the ore will not exceed \$2 per ton.

Extraction percentages are based on the samples taken at the head of the mill by the sampling plant and calculated against the tailing sample taken below the filter. It is said that the bullion return checks closely with these calculated results.

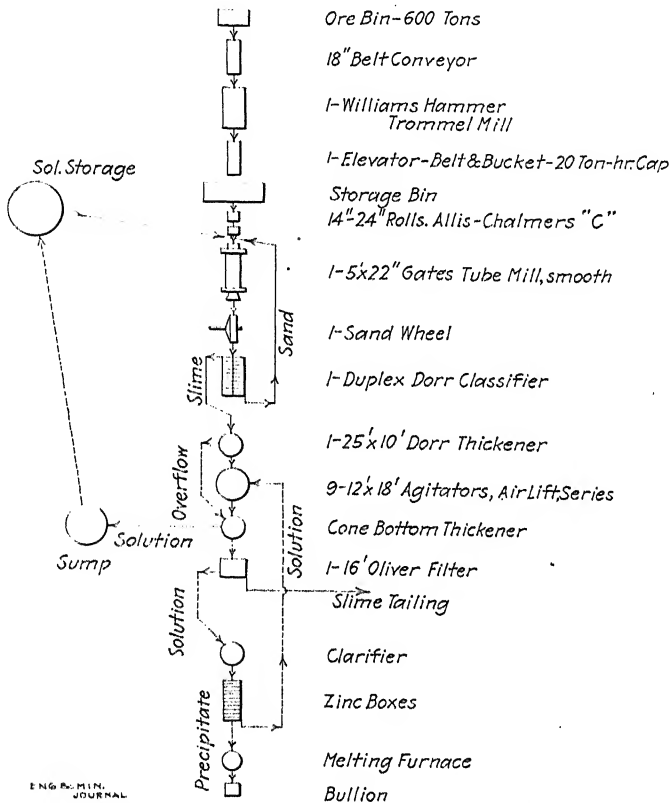
The precipitate is not acid treated, but is melted with flux in a Steeple Harvey furnace. The refinery department is situated at the head of the mill and in a separate building.

A New Crushing Machine. The mill of the San Poil Consolidated Co. is the only other plant operating at the present time in the Republic district and is situated in a cañon some little distance north of the town. The mill has been recently completed and is operating on ores of much the same character as those referred to in connection with the North Washington mill, hard, close-grained quartz.

Railroad cars deliver the ore into the bin at the head of the plant and from this bin an 18-in. belt conveyor delivers it to a Williams hammer trommel mill. This machine is unusual in milling plants. It is constructed much like the Quenner dry placer machine which was devised at the Altar field in Sonora, Mexico. It consists of a trommel built of heavy bars spaced $\frac{1}{4}$ in. apart, revolving at 100 r.p.m., and a central shaft running through it revolving at 600 r.p.m. Upon the central shaft are 32 hammers weighing 16 lb. each connected with the shaft by heavy chains. The hammers swing so that there is no danger of their touching the trommel. Ore is introduced at one end of the machine and the hammers, flying out by centrifugal force, strike the pieces of rock and shatter them. Several kinds of metal have been used in making these hammers, which receive the major part of the wear, and at present the most available material has proved to be mild steel, sawn from the bar, and drilled to receive the chain connections. Wear of the hammers has diminished from an original to

or more pound per ton of rock crushed to a point where it is not much more than 0.5 lb. per ton.

The machine certainly does an immense amount of work, reducing mine run to a granular product at one operation. The product is supposed to come out through the trommel bars at $1\frac{3}{8}$ in., the distance between the bars, but there is a good deal of it which is considerably larger, presumably due to wearing of the bars, thus enlarging the openings. In



FLOW SHEET OF THE SAN POIL CONSOLIDATED MILL.

operation the machine makes an enormous amount of dust as the dry ore is broken up. When damp ore is used the quantity of dust is not so great and the general product is finer, but its capacity is much reduced. Sizing tests on the product show as high as 40% of the product passing a 20-mesh screen, of which 65% is finer than 10-mesh and 6% through 200-mesh screen. About 70 tons per day are being milled through the machine. Its capacity is 10 tons per hour.

It is acknowledged that this machine is still in the experimental stage, although the operators believe it will continue to perform its work as at

present. The machine now installed is to be exchanged for another similar one built much heavier, but designed to do the same work in the same way. It will, however, require incontestable proof to show that a machine of this kind can be built strong enough to stand the enormous strain of reducing mine-run ore to $\frac{1}{4}$ in. or even $\frac{1}{2}$ in. at one operation by such strenuous means and be economical.

Sampling the fine ore is done automatically, and after passing the rolls, as shown in the accompanying flow sheet, it is sent to a 5' x 22-ft. tube mill which is in closed circuit with a duplex Dorr classifier.

Air Agitation Methods. The slime from the classifier is thickened in a Dorr thickener 25 x 10 ft., and the thickened pulp taken to a series of nine agitator tanks, each 12 x 18 ft., with cone bottoms and using air agitation. In addition to the central air lift in these agitators, which are cut off below the surface as is done in the tanks at Grass Valley, to be mentioned in the following paper, there are three additional lifts in each tank, designed to avoid settling of slime on the cone bottoms which are too flat to do this automatically. Treatment through the tanks is continuous and solution from 5 to 7 lb. KCN per ton is used. At this mill the stronger solutions are used in the tube mill, the weaker ones being made up at the agitators. The time of agitation is 50 to 70 hr. in the tanks.

From the final agitator of the series the pulp is taken to a cone-bottom thickener and thence to an Oliver filter, 16 ft. drum, where filtration is effected. The pregnant solution is passed through zinc boxes using shavings and the barren solution issuing is passed back to the final agitator of the series of nine, thus diluting the pulp and giving it a wash before going to the thickening box and filter. Solution overflowing from the thickener is pumped back to storage to be used over again.

The ore averages \$8 per ton in value and 92 to 95% is extracted. Consumption of KCN is 1.5 lb. per ton and CaO 2.3 lb. per ton.

There is nothing particularly novel about this plant with the exception of the Williams mill above mentioned, but it is another link in the chain of recent events which have shown clearly that the ores of the Republic do not deserve the reputation they have received for being difficult to treat and that when use is made of the means which have been developed within the last few years for the better working of the cyanide process, together with the essential and vital point of the metallurgy as applied to this particular rock, extremely fine grinding, there is no difficulty in beneficiating it cheaply and efficiently.

Neither of the mills at present in operation is perfect nor is to be taken as a model of its kind, but considering the difficulties in the way of getting sufficient capital to treat ores which had already been tagged as hopeless, they are good, and too much credit cannot be given to the men who have made a metallurgical success where inevitable failure was freely foretold.

CHAPTER XVI

THE MILLS OF GRASS VALLEY, CALIFORNIA

The North Star Mines Co., situated near the town of Grass Valley in Nevada County, Calif., operates two mills, one built at the shaft of the mine, known as the North Star mill, and one situated in a cañon near the town, known as the Central mill. The Central is the newer mill, built much later than the old North Star mill. They are both 40-stamp installations and treat about the same quantity of ore in exactly the same way, the only difference being that the older mill does not attempt to treat the concentrate made in it, but sends it to the Central mill for reduction. Owing to these facts the Central mill will be discussed in his paper, its system typifying the practice established by the company and illustrating the method of concentrate treatment.

Occurrence of Gold.—The ore is a free-milling quartz in which quantities of sulphides occur, and it is principally in these sulphides that its value lies. The principal valuable metal is gold; silver exists in small proportion, but not sufficient to justify any special metallurgical efforts to recover it. The gold is principally in mechanical association with the sulphides, only a small proportion being in chemical combination. In crushing, the ore may be said to be of medium hardness. It consists principally of quartz.

Each of the mills of the company contains 40 stamps, and the combined capacity of the two is about 9000 tons per month, or about 300 tons per day. The average ore treated in the mill is valued at about \$10 to \$12 per ton.

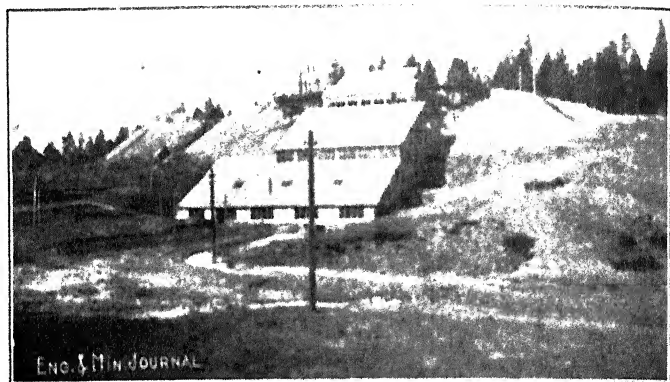
Stamp-crushing Practice.—The ore is brought to the Central mill in small cars drawn by a light electric locomotive. It is dumped into a general bin from which it passes over a grizzly, the coarse rock being reduced in size in crushers of the Blake type and the whole finally received in the battery bins.

The construction of these bins is noteworthy in that they are entirely of masonry, forming a massive and solid foundation for the crushers. They are built directly on the hillside and are a fine example of permanent construction.

From the battery bins the ore is drawn through disk feeders into the mortars. There are 40 stamps of 1000 lb. each dropping 110 times per

and there is also an outside lip plate. The regular apron plates follow as is usual.

The screen in use is somewhat unusual, consisting of a light sheet-steel plate punched with small round holes. These holes are grouped in small squares of about 1 in. on a side, and the squares are separated by ribs of the solid metal, about as shown in the illustration. The size of



CENTRAL MILL.

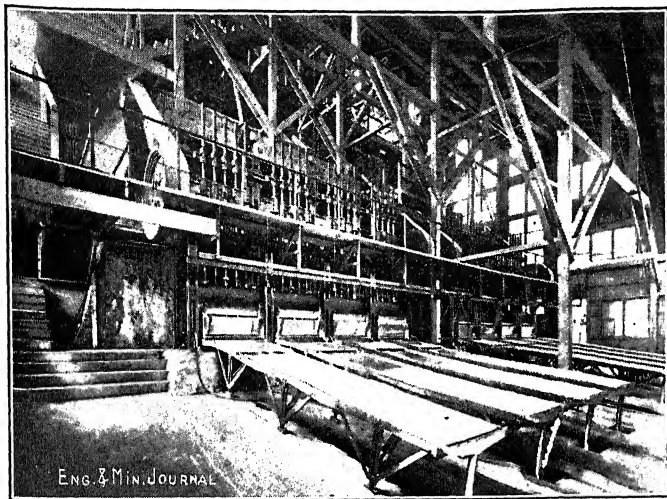


CENTRAL CYANIDE PLANT

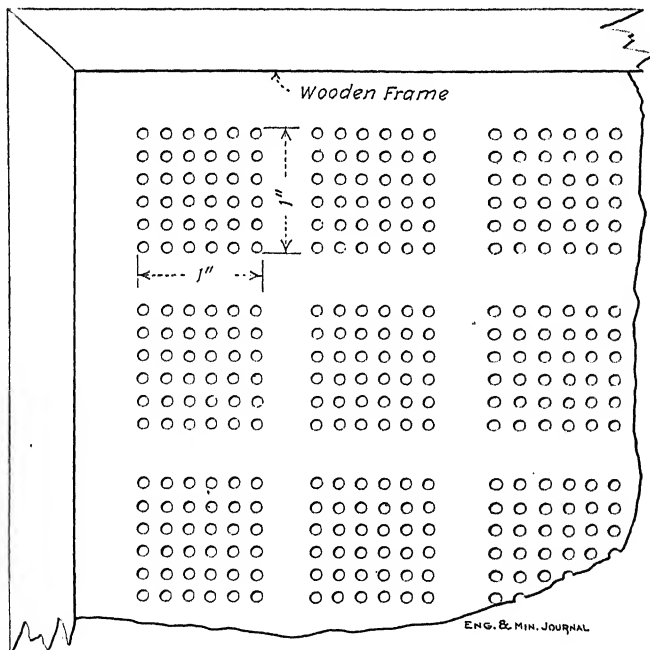
NORTH STAR MINES, GRASS VALLEY, CALIF.

the holes is such that they approximate the opening generally found in a 30-mesh wire screen. The separating ribs add strength to the screen. The whole length of the mortar, with a width of about one foot, is occupied by the screen which has no strengthening strips aside from the ordinary wooden frame used to retain it.

The battery framing is entirely of steel. The driving arrangement is a little out of the ordinary as the motor is situated above the batteries and



STAMP BATTERY AND PLATES, CENTRAL MILL OF NORTH STAR MINES.



SCREEN USED AT NORTH STAR MILL.

the driving belts lead down, with one reduction, to the camshaft. The accompanying illustration shows this arrangement. By this means the battery motor is given a firm foundation on the masonry of the bins and all belts and pulleys are easily reached when desired.

From the plates the pulp is led to a series of concentrators which are round, of the buddle type, but have a reciprocating motion, revolving back and forth about a central point, through a small arc. The concentrate is removed at a point on the edge of the circle. An arrangement is made for reconcentrating the middling of a number of these tables on others. The machine is known as the Dodd buddle.

From the concentrators the pulp flows to the cyanide plant, which is separate from the mill and situated at some distance from it. All crushing and concentration is done in water and the pulp flows by gravity to the cyanide-treatment plant.

Cone System of Classification. All the pulp is received at the cyanide plant in a roughing cone, 7×6 ft. The overflow from this cone goes immediately to the cyanide department as slime, the object being to take out the majority of the slime, and slime only, leaving the cone underflow to be further classified in a separate system. This system consists of three cones, each 5×5 ft., using an upward current of water to assist in the classification. One of these cones has straight sides, but of approximately the same size as the other two, and its operation is the same. Clean separation is accomplished in these cones and their overflow joins the stream of slime from the roughing cone and forms the slime portion of the pulp.

Separate Sand and Slime Treatment. The underflow of the cones is taken directly to the leaching tanks where the first cyanide solution is put in contact with it.

The leaching tanks are six in number, each 22 ft. 5 in. by 87 in. and are served by distributors of the Butters type. The cyanide treatment occupies about seven days in total. At first a wash of lime water is applied to neutralize any acidity in the ore and prepare it for the cyanide solution which follows. After this has been drained away a bath of 30 tons of pregnant solution from the filters is applied which has strength of about 0.035% KCN. This is immediately drained and is followed by a bath of barren solution containing 0.1% KCN. The tank is filled with this solution, which is allowed to remain in contact with the charge for 24 hr. with the tank outlets closed meanwhile. After this soaking period, the solution is allowed to drain into a special solution tank until it shows a strength of 0.06% KCN, when it is turned into the strong sump, where it finally reaches a strength of about 0.09% KCN. Other strong washes are followed by washes of solution from the filters and finishes with the barren solutions which are to be wasted after being precipitated, and

finally a water wash is applied. The sand, after treatment, is sluiced out of the tanks. There is no scarcity of water.

The slime is all collected in a series of cone-bottomed settling tanks, assisted by one Dorr thickener. There are six of these settling tanks, three of which are 14×15 ft. and three 13.3×9 ft. The Dorr thickener is 19.5×13.5 ft., and is arranged to make one revolution in 3 min. 50 sec. The slime is thus dewatered, leaving a pulp having specific gravity of about 1.3 and a dilution of 2:1, approximately.

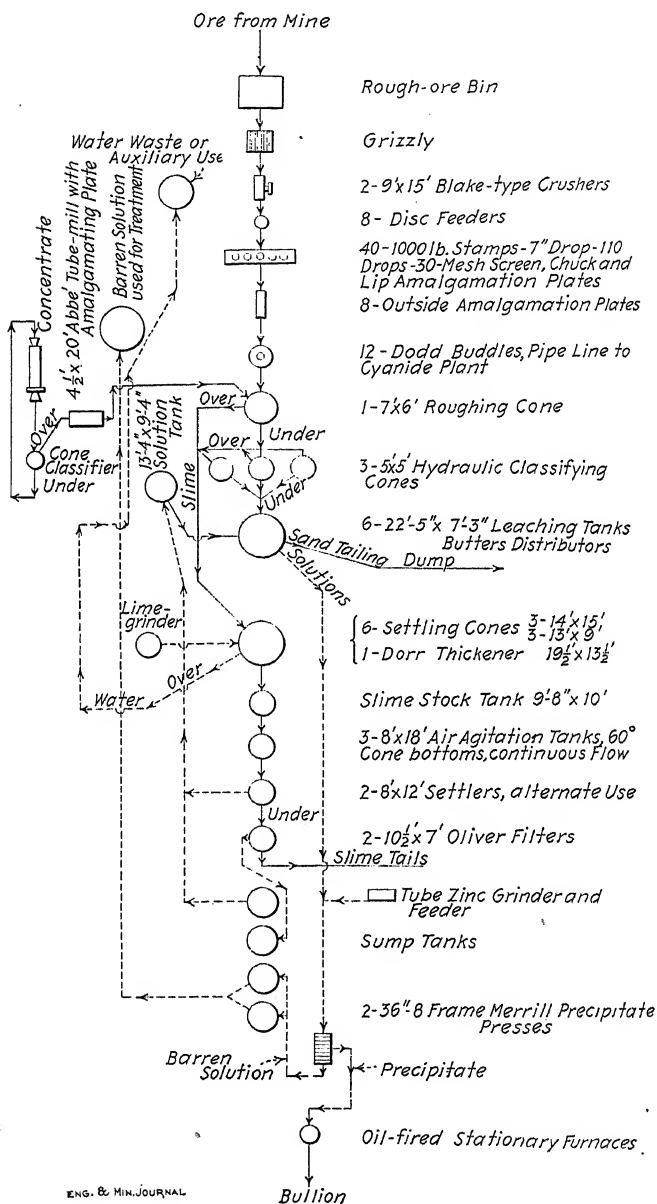
In a system of this sort, where an appreciable amount of water is taken into the cyaniding system, it is evident that it will have to be discarded at some point. This introduces a condition somewhat difficult to handle and it is only where weak solutions are used that it is practicable. At the Central mill weak solutions are used in slime treatment and for leaching the sand. With sand treatment by leaching it is possible to reduce the incoming moisture to about the same quantity discharged with the tailings, so that in this department there is little or no accumulation of surplus solutions. This can be accomplished with slime also, but is an expensive process, in fact it was tried at the Central mill at one time but it was soon found to be more economical to waste a selected, precipitated solution, with its cyanide content reduced to the lowest possible point, than to undertake the expense of more complete dewatering.

Slime Treatment System.—The partially dewatered slime is recovered in a stock tank, from which it is taken to the agitation department and the necessary cyanide added to bring up the strength to the treatment standard of 0.035% KCN. The slime, with its added cyanide and solution, goes then to the treatment tanks.

The tanks used for agitation are 8 ft. diameter and 18 ft. deep and have cone bottoms of 60° inclination. The agitation is by means of a central lift pipe. It will be noted that these tanks are practically Pachuca tanks, except that the lift pipe does not reach the surface of the pulp, a feature which has been adopted with some advantage in a few Pachuca installations. Air is used for operating the lifts. It is of interest to note that these tanks are said to have been installed and in use before the Pachuca type, as such, came into existence.

The agitation of the slime pulp is continuous through the three agitators, the time of passage being calculated at approximately 14 hours.

Continuous Filter System.—The pulp from the agitators is collected in two settlers, used alternately, each 8×13 ft., equipped with cone bottoms. Settling and decantation proceed simultaneously, the thickened pulp meanwhile being drawn off for filtration. In about eight hours, one settler is filtered so that the overflow is not clear, when the pulp is transferred to the other settler, the first one being allowed to settle, the solution decanted, and the thickened underflow drawn off as it settles.



The thickened pulp is taken to the filters, this installation consisting of two $10\frac{1}{2} \times 7$ -ft. Oliver continuous revolving machines. It was at this mill that the Oliver filter was conceived and developed and the two machines now in use are the first of their type to be built.

The tailing is sluiced away from the filter and run to waste. About 60 tons of slime daily are treated on the two filters.

The Merrill system of precipitation is used. Zinc dust added to the pregnant solution is pumped through two Merrill presses, each of which contains eight frames, the frames being the 36-in. triangular type. These presses originally had the solution discharge at the bottom of the frame, but pipes have been fitted to the discharges and carried above the level of the frames so that the press always remains full even in case of cessation of operations of the plant. The frames thus kept full of solution prevents oxidation of the zinc consequent upon an empty frame and resulting contact of air with the zinc. All solutions to be precipitated are first used as washes on the sand-leaching tanks, enriching the solutions and effectually clarifying them. The precipitate is melted in stationary, oil-fired furnaces without any preliminary treatment whatever. A small tube mill is used for emulsifying the zinc dust with solution before its addition to the solution to be precipitated, and a mechanical feeder introduces the zinc into the tube mill.

Concentrate Treatment.—The concentrate treatment is unusual and worthy of particular note. The two mills of the company make six to seven tons of concentrate daily, all of which is treated at the Central mill. It is brought to the mill in cars and is dumped into a concentrate bin, being meanwhile mixed with lime at the rate of about nine pounds per ton. From this bin the concentrate is mechanically fed into a tube mill of the Abbé type. The mill is 4.5 ft. in diameter and 20 ft. long and revolves at 19 r.p.m. The concentrate is reground in this mill, and issuing, it is classified in a cone classifier. The fine overflow all goes over an amalgamating plate and the underflow is returned to the tube mill, forming a closed circuit from which there is no exit save through the overflow of the reclassifying cone. All of the reground concentrate pulp, after having passed this regrinding and amalgamating system, is taken directly to the large roughing cone, before mentioned, at the head of the cyanide plant, where it enters treatment along with the bulk of the ore.

Thus the concentrate, after having been removed from the pulp, is ground, amalgamated, and returned to it and undergoes exactly the same treatment as the siliceous part of the ore. This treatment is said to be altogether satisfactory, the regrinding being sufficient to liberate most of the contained gold, a part of which is recovered on the plate and the remainder in the cyanide treatment. The portion which goes to the cyanide plant is amenable to the short-time and weak solutions used there.

The explanation, of course, is that the gold is only mechanically combined with the sulphides and is liberated by the additional grinding. In the case of chemical combinations other means would be necessary for its satisfactory extraction.

This is a good illustration of the utility of experimental work, for it has here fitted an inexpensive process to a material which needs nothing else. A separate treatment, such as is usually considered necessary with sulphides, might have been considered necessary in this case and an expensive plant and treatment system might have been installed had not thorough experiment shown the exact requirements of the material.

The concentrate varies in value from \$30 to \$80 per ton and the extraction is about as complete as with the siliceous portion of the ore. As has already been said, the mill head averages \$10 to \$12 per ton, and the head of the cyanide plant averages about \$2 per ton, before the concentrate is added. The total extraction obtained from mill and cyanide plant approaches 98%. In the cyanide plant alone, about 94% of the gold in slime is recovered and 85 to 90% of that in the sand. The tailing contains on the average about \$0.20 in gold value.

Consumption of Material and Cost.—The consumption of cyanide is 0.61 lb. per ton milled; of zinc, 0.216 lb. per ton; of lime, 4.21 lb. per ton, and of pebbles, 4.5 lb. per ton of sulphides ground.

The cost of treatment is given in the accompanying table.

	Milling	Concentration	Cyaniding
Labor.....	\$0.176	\$0.087	\$0.166
Material.....	0.075	0.017	0.186
Power.....	0.129	0.027	0.116
Total.....	\$0.380	\$0.131	\$0.468
Milling.....	\$0.380		
Concentration.....		0.131	
Cyanidation.....		0.468	
Total.....		\$0.979	

The Empire Mill.—The Empire mill is also near the town of Grass Valley. The mine and mill are close together, although as in the case of the Central, the milling and cyanide departments are in separate buildings.

The ore at the Empire mill is like that at the North Star, a free-milling quartz containing sulphides. The mill is similar, and in fact, the treatment is almost identical, so that it will not be necessary to make a detailed study of that practice, but attention will only be called to the few points of difference.

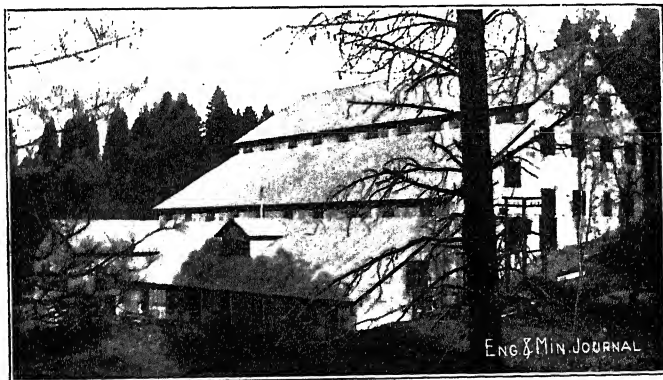
The Empire mill contains 40 stamps of 1050 lb. each and amalgamation is practised both inside and outside the mortars. The quantity of

ore milled is from 140 to 150 tons per day, about the same as the North Star mills. Concentration is practised as is the case at the other mills.

The mill pulp flows through a pipe line to the cyanide plant, where it is received in two roughing cones, the slime overflowing and going directly to settlers and the underflow passing for further classification to four hydraulic classifying cones, which make the final separation into sand and slime.



EMPIRE MILL.



EMPIRE CYANIDE PLANT.
GRASS VALLEY, CALIF.

The sand is taken directly to the leaching tanks and is delivered into them by means of Butters distributors. A feature of the practice both at the Empire and Central mills is that the Butters distributors are used both in filling the tanks and also in sluicing out the residue. For sluicing out the sand, water is admitted through the distributor, the bottom gate

opened, and sluicing proceeds automatically. The filter bottom of the tank is made slightly inclined, in order to facilitate the discharge. The sand tanks are 14 ft. by 9 ft. 4 in., and contain approximately 155 tons. The treatment occupies six days and the strong solution is 0.10% KCN, as in the case of the Central mill.

Settling Area.—The slime from the classifiers is taken to the settlers. There are four of these, each 24 ft. in diameter and 22 ft. deep, with cone bottoms. The pulp is distributed among them as conditions dictate. This settling capacity seems extensive for the quantity of slime handled, about 65 to 70 tons daily, but it is stated that the settling, even with this great capacity, is accomplished only with great difficulty. A large quantity of lime is added to assist settlement, most of this lime being lost in the overflow water, which is either run to waste or used in auxiliary operations about the plant, there being none returned for further use in milling.

It is an object to draw the slime from these settlers with as little moisture as possible, the dilution usually being about 1:1. As the thickened pulp reaches the agitation department it is diluted to about 2:1 with fresh solution and is made up to 0.04% cyanide strength.

The agitation is continuous through four tanks of the Pachuca type, each 10×18 ft. The cyanide strength is made up in the first and last tanks of the series and a low protective alkalinity maintained. There is no thickening or washing of the pulp after agitation except that given in the filters, to which the pulp is taken directly from the agitation tanks. The filter installation consists of two Oliver machines of the 8-ft. size.

As at the Central mill, all solutions to be precipitated are first used as washes on the sand tanks in order to clarify them. The Merrill system of zinc-dust precipitation is used, and there are two triangular frame presses, 36-in. frames, having nine and ten frames respectively. These presses have pipe connections for the solution outlets which deliver above the level of the top of the frames. The precipitate is acid treated and melted.

The concentrate treated, about four tons daily (part of which is purchased), is reground in a 4×8-ft. Allis-Chalmers tube mill, run over plates and classified at the cyanide plant in a separate cone, the overflow of which joins the stream of slime to the settlers and the underflow, the product going to the sand-leaching tanks. This separate classification is the only detail in which the concentrate treatment differs from that in use at the Central mill.

The general arrangement at the Empire mill is somewhat less complicated, as it is understood that the mill stands exactly as designed and the necessity for inconvenient remodeling has been avoided.

The Grass Valley properties present mining in its most attractive form. Situated in a fertile agricultural district, free from climatic extremes and

surrounded by luxuriant vegetation, the aspect differs widely from the usual mining camp. The district is old, the first discovery was in 1850, and proven, so that makeshifts and cheap construction have long since given place to substantial installations, an artistic eye having evidently been concerned in the general plans. This is especially true at the Empire where stone buildings and pleasant foliage give an appearance more like that generally presented by well designed and permanent habitations than mining camps. Those concerned in the operation of these mines are fortunate indeed in their habitation.

CHAPTER XVII

THE BLACK OAK PLANT, CALIFORNIA

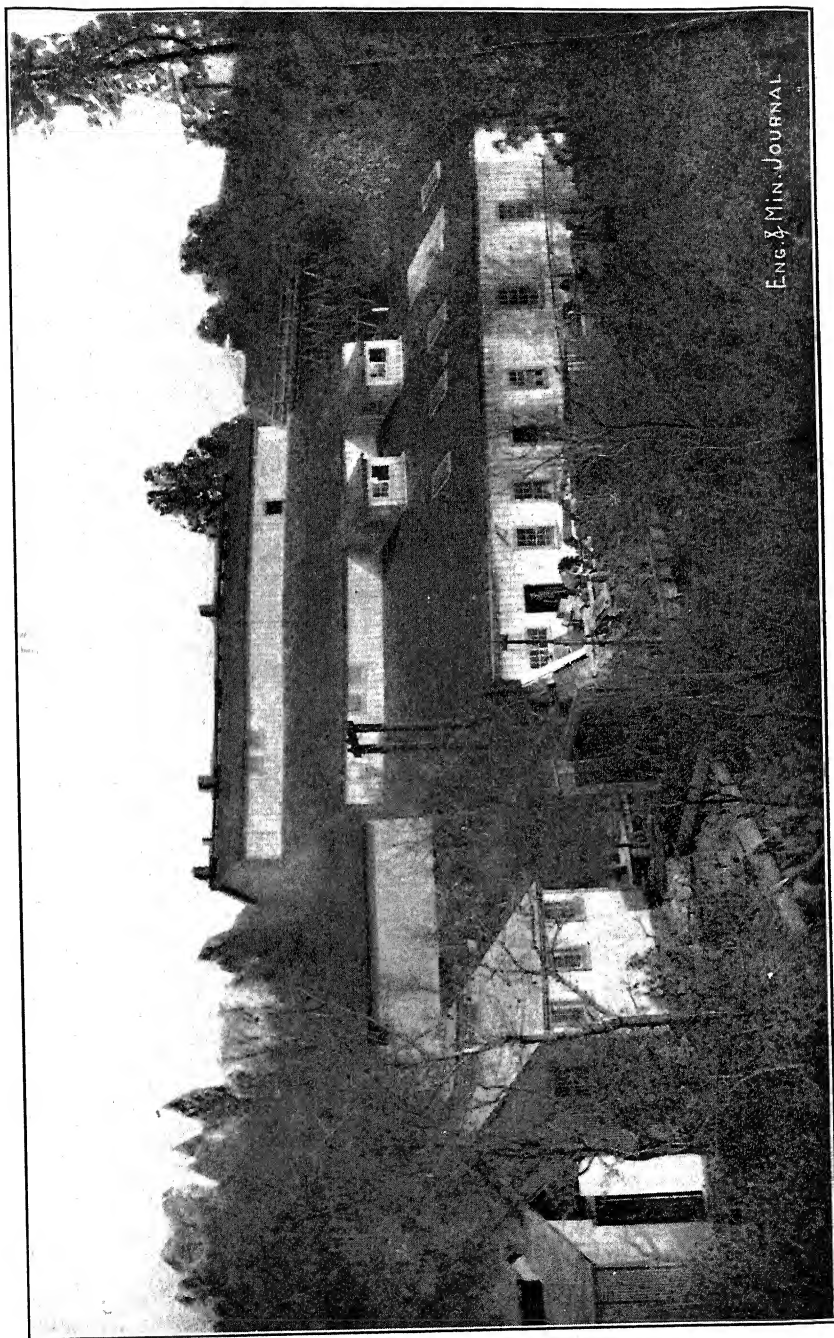
Near the town of Soulsbyville, in Tuolumne County, Calif., is situated the plant of the Black Oak Development Co., said to be the only mill at the present in the State of California which employs the total-sliming, continuous-agitation process of treatment. The property is in an agreeable district where climatic conditions are good and the natural surroundings pleasant.

Ore Character.—The plant is near the town of Tuolumne, the terminus of the branch line railroad by means of which the district is reached, from Stockton, via Oakdale.

Gold and silver both occur in the ore of the Black Oak mine, and the proportion is 2 or 3 parts of silver, by weight, to one of gold. In this proportion the gold is, of course, by far the most important factor to be considered in the metallurgy of the ore, but, as will be mentioned later, the silver is in sufficient quantity to make advisable a special effort to recover a goodly proportion of it.

Most of the valuable metal is in quartz which occurs in a granite-diorite country rock, and sulphides contain the greater part of the silver and gold. As often happens in California ores, this gold does not seem to be chemically combined with the sulphides, but only mechanically, so that fine grinding liberates the greater part of it. The silver is, of course, largely in combination as sulphide, in which condition it is amenable to cyanidation after having been subjected to fine grinding.

Comparison with Other Ores.—It is noteworthy that the ore deposits of the Black Oak mine, and of the surrounding district similar in a general way to the mineral already described at Grass Valley, are said to be similar to the majority of ores in the mines on the Mother Lode, and identical with some of them. If this is true, the question immediately is suggested as to why the other Mother Lode mines, or at least some of them, do not make use of cyanidation, a process which has demonstrated its efficiency and economy on similar material. Mother Lode ores are still being beneficiated by old methods, amalgamation and concentration. While both of these systems are simple and cheap, it is undeniable that neither of them approaches cyanidation in the amount of recovery from simple ores. Some have informed me that Mother Lode ores are not treatable by cyanidation, while others have assured me quite as emphatically that they are.



BLACK OAK MILL, SOULSBYVILLE, CALIF.

In view of results obtained at Black Oak and Grass Valley, the preponderance of evidence would seem to be in favor of the latter statement. Perhaps the experience of these two camps will be of value to those operators on the Mother Lode who desire to increase the efficiency of their installations.

The Crushing System. Ore from the mine is first delivered to the mill bin which has a capacity of about 185 tons. Four Challenge feeders deliver it into the mortars of a 20-stamp crushing plant, each stamp weighing 1250 lb. and dropping 102 times per minute through 6 in. Mortars are of the narrow pattern designed for rapid crushing. Three of them are equipped with ton-cap screens having 19 apertures per inch, and the remaining mortar has a 6-mesh, square aperture screen. This coarse screen adds sufficient granular material to increase the efficiency of subsequent tube mill work. Many of the recently constructed mills are adopting the system of varied feed for tube mills and the results thus far seem to have amply justified the practice.

The Black Oak mill was originally a 40-stamp plant, containing the old-style stamps of light weight, but it has been entirely rebuilt with new and appropriate machinery. There is still room for 40 stamps under the present room, in fact 20 of the original stamps are still there in a more or less dismantled condition. With further mine development all available space may be required.

Classifying and Regrinding. Pulp from the stamps flows by gravity to a Dorr classifier of the usual type in which the slime is separated and taken directly to treatment and the sand is delivered to a tube mill for further grinding. This tube mill is 5×18 ft. and is of the type made by the Power & Mining Machinery Co. It is operated at 26 r.p.m. and requires 48 hp. to keep it moving. Imported pebbles are used, the consumption of which is 5 lb. per ton of ore crushed. The hardness of the ore is attested by this consumption of pebbles which is extraordinarily high.

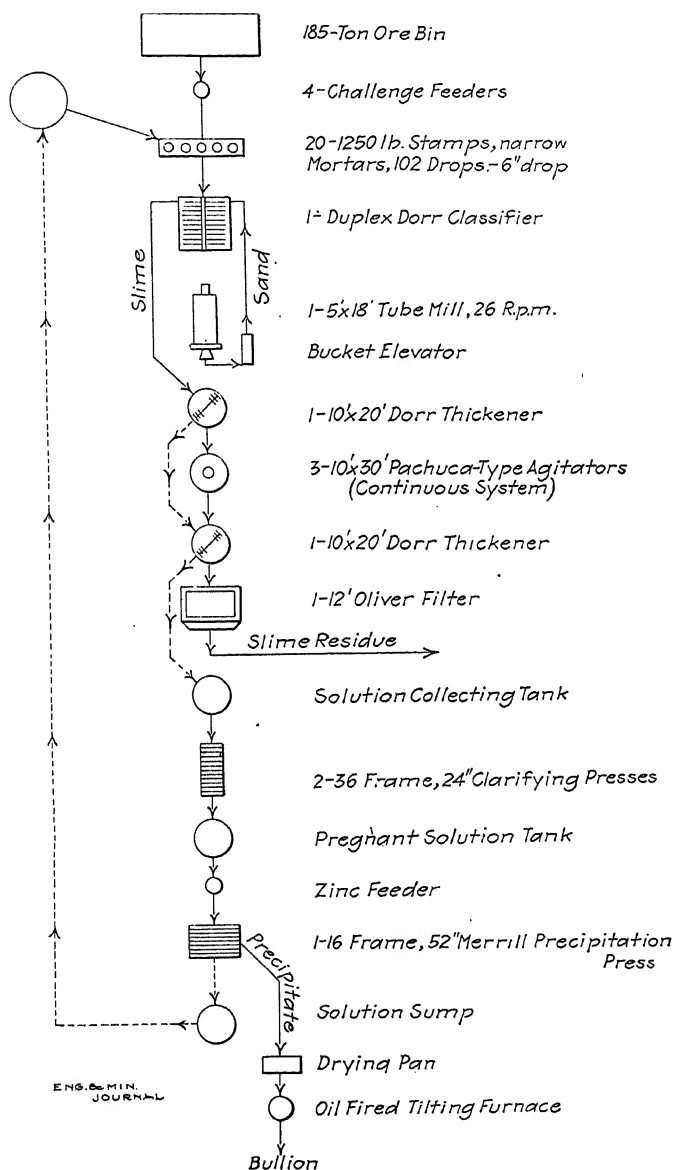
Ground product from the tube mill is returned to the classifier by means of a bucket elevator, thus forming a closed circuit, the only exit from which is the slime in condition for agitation treatment.

Upon its exit from the classifier, the slime proceeds to a 10×20-ft. Dorr thickener, where a portion of the solution is decanted and a thickened pulp delivered of proper consistency for the subsequent cyanidation.

Agitation of the Slime. Slime treatment is performed in tanks of the Pachuca type of which there are three, each 10×30 ft. Passage of the pulp is continuous through these tanks and during the time of agitation the extraction of the contained gold is practically complete.

The Dorr thickener, which prepares the pulp for the agitation tanks, delivers a pulp in which the proportion of slime to solution is about 1:1½.

The thickener is operated at about one revolution in six minutes, and in common with these machines, requires an extremely small expenditure of power.



FLOW SHEET OF BLACK OAK MILL.

The material agitated is true slime, or colloid, only in small proportion, the major part consisting of extremely fine granular matter. About 78%

of it is sufficiently fine to pass a 200-mesh screen, while 98 to 99% will pass a 150-mesh aperture. Pipe connections for the continuous passage of the pulp are 4 in. in diameter.

Continuous Filtration.—Issuing from the agitation treatment in the Pachuca tanks, the pulp is received in a second Dorr thickener, identical in its dimensions with the one first mentioned. Just before reaching this thickener, the pulp is diluted with the overflow product of the first thickener and the mixture thickened to a point where the underflow of pulp issuing contains solution and solid in a 1:1 proportion.

This thickened pulp is delivered to a 12-ft. Oliver continuous filter. The slime residue is dewatered and discarded and the solution, together with the overflow from the final Dorr thickener, is gathered in a collecting tank from which it is taken to the precipitation system.

For precipitation the Merrill system, using zinc dust, is followed. A special zinc-dust feeder drops the precipitant into the stream of pregnant solution going from the tank to the suction of the pump, and the mixture is forced through a 16-frame filter press of the Merrill type. The frames of this press are 52 in. across the top and are triangular in shape as is usual.

Solution, after precipitation, is received in a sump from which it is pumped up to the solution storage tank for further use in the mill.

Precipitate from the press is partially dried in a drying pan, fluxed and melted in a tilting, oil-fired furnace. The accompanying flow-sheet diagram illustrates the metallurgical process followed in the mill and the principal machinery installed.

Character of the Dry Slime. The Black Oak ore is hard, as has already been mentioned, and remains largely in the granular state even after continued grinding. The specific gravity of the dry slime in the condition in which it is subjected to agitation treatment, is about 2.8, a figure which is rather high in comparison with ordinary siliceous slimes, which generally contain a greater proportion of colloid matter.

The mill will treat about 100 tons per day of 24 hours, but at present the rate of crushing is near 85 tons daily. Average run of ore will contain a combined gold and silver value of \$15 per ton in the proportions which have already been mentioned.

Of the gold, 97% is usually extracted without difficulty, and about 92% of the silver. Treatment solutions contain 0.2% KCN and 0.15% CaO. Lime is added at the batteries and in the agitators. Litharge is used as a source of lead for removing soluble sulphides from solution and is added at the tube mill in order to facilitate solution.

Chemical Consumption. The consumption of chemicals and supplies is low, as is usual when treating an ore whose value is largely in its gold content. The cyanide consumption is 1.0 lb. per ton; of litharge, 0.35 lb.; of lime, 3 lb.; of zinc, 1 lb., and of pebbles, 5 lb. per ton.

TABLE OF COSTS AT THE BLACK OAK MILL, CALIF., BASED ON MILLING
2202.5 TONS

Supplies	Per Ton	
Rock crusher.....	\$0.0121	
Batteries.....	0.0158	
Tube milling.....	0.0349	
Tube-mill liners.....	0.0266	
Classification	0.0039	
Refining.....	0.0195	
Repairs.....	0.0131	
Office and general superintendent.....	0.0042	
Assaying.....	0.0241	
Marketing bullion:		
Control..... \$10.45		
Treatment... 167.38		
Express..... 25.25.....	0.0922	
Cyanide.....	0.2018	
Lime.....	0.0111	
Litharge.....	0.0507	
Zinc.....	0.0970	
Pebbles.....	0.0780	\$0.6850
		<hr/>
Power and lights.....		\$0.3500
Insurance.....		0.0200
Labor		
Rock crusher.....	\$0.0453	
Tramming.....	0.0844	
Batteries.....	0.0968	
Tube milling.....	0.0184	
Classification.....	0.0192	
Agitation.....	0.0223	
Thickening.....	0.0223	
Pumping and elevating.....	0.0244	
Filtration.....	0.0246	
Clarification.....	0.0224	
Precipitation.....	0.0236	
Refining.....	0.0305	
Repairs.....	0.0523	
Office and general superintendent.....	0.0715	
Mill superintendent.....	0.0681	
Power and light.....	0.0165	
Assaying.....	0.0315	\$0.6741
		<hr/>
Total mill costs.....		\$1.7291

Seven men, excluding the superintendent, are required for mill operation, and 130 hp. is the average consumption of energy for moving the machinery. While the mill is small and handles only a limited quantity of ore, costs have been reduced to an extremely reasonable figure as is

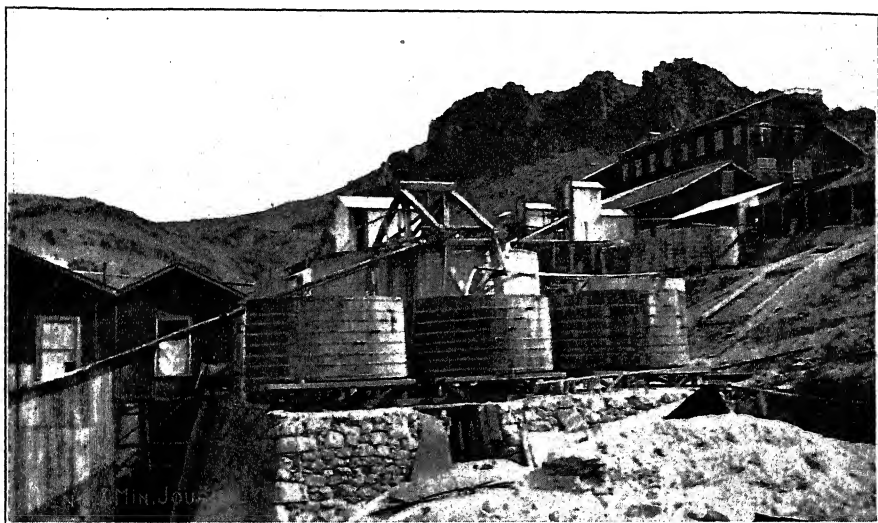
shown by the accompanying tabulated list of items. During the two months following that in which this report was made, a general reduction of costs has been accomplished, the total being reduced to about \$1.61 per ton. The operators are fortunate in having an ample supply of water and conditions generally favorable for successful operation.

CHAPTER XVIII

THE GOLD ROAD MILL, ARIZONA

The mill of the Gold Road Mines Co. is situated at Gold Road, about 20 miles from the town of Kingman in western Arizona. Railroad communication is established at Kingman and connection with the mine is by wagon road over which freight is hauled by horses, and passengers by automobile stage. The region is arid, water is scarce and has to be conserved with care.

Local ores have gold as the principal valuable constituent, the metal being finely divided and distributed through a gangue consisting of quartz



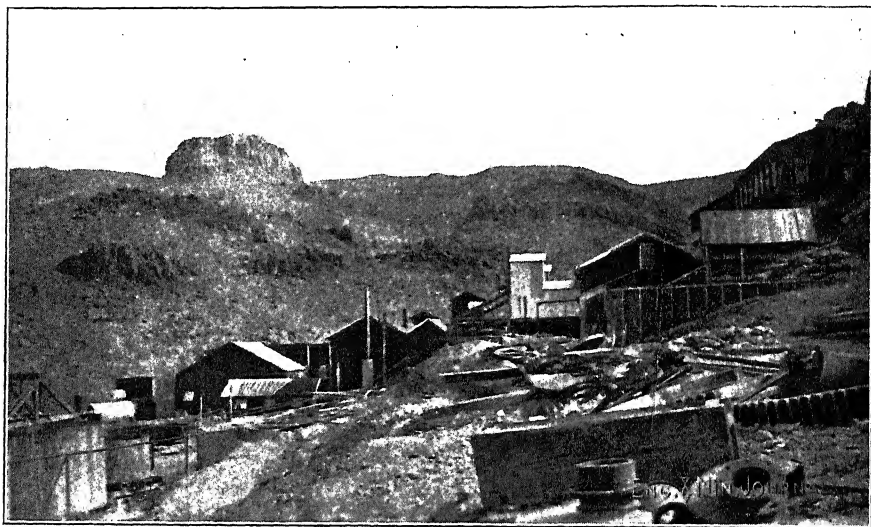
GOLD ROAD MILL, GOLD ROAD, ARIZ. LOOKING TOWARD THE CRUSHING PLANT.

and some calcite in a country of andesitic rock. There is no great quantity of sulphides, the gold being free and principally fine. On account of the fineness and wide distribution of the gold, a rather high degree of crushing is required and the total-sliming process is followed.

The mill is not an original construction, but rather a development, the remnants of machinery used in various processes, now relinquished, remain as reminders of the older systems of metallurgy. This changing of systems has also resulted in a scattering of the reduction plant over a good

deal of territory, a fact which may be seen by a study of the accompanying engravings. Notwithstanding this circumstance, a plant of exceedingly good metallurgical performance is now in operation, the details of which are explained in this paper.

Preliminary Breaking.—Installed at the mine is a No. 5 Gates gyratory crusher where the ore receives its preliminary breaking. From the crusher it is trammed to the mill, where it is delivered into a 1540-ton bin which supplies the mill as required. During the preliminary breaking at the mine, the required portion of lime is added to the ore so that by the time the material has passed through the bin and entered the stamp-crush-



GOLD ROAD MILL, GOLD ROAD, ARIZ. UPPER SIDE VIEW.

ing department, the lime has performed a great deal of its essential work, neutralizing the developed acidity and becoming more or less slaked and ready to offset the acids which may be formed later in the course of its treatment. This method of lime addition is advocated by many operators because of the advantages enumerated above, and further, because the lump form is progressively crushed as is the ore, and develops alkaline conditions, when the addition is at the appropriate rate, just as the ore develops acidity. Others advocate the powdered form of lime, sometimes previously slaked, and make additions at the point and time when acidity develops. No doubt a greater percentage of CaO can be dissolved by careful slaking under favorable conditions, but whether the highest ultimate economy and efficiency are reached by so doing, is a question which will have to be solved for every problem after consideration of all the conditions.

Crushing and Grinding.—From the bin, Challenge feeders deliver the ore into a battery of forty 1050-lb. stamps, making 104 drops per min. through 7 in. The stamp crushing is done in solution. Screens of 4-mesh are used on the batteries, the stamp duty being about nine tons per stamp per day, or a total of 360 tons daily for the mill.

Pulp from the stamps is led to two distributing cones, one 4 ft. and one 6 ft. in diameter, from which it goes to six duplex Dorr classifiers, where the overflow slime is removed and the sand dewatered and delivered to the tube mills for regrinding.

There are four tube mills, each 5×22 ft, used in closed circuit with the classifiers, the delivery from the tube mills being elevated with 10×54 -in. Frenier pumps and returned to the classifiers where any sand not sufficiently fine for treatment by agitation, is removed and returned to the tube mill for further grinding. El Oro linings are used in these mills and are said to be entirely satisfactory, each lining lasting a year before it is replaced. Imported pebbles are used in the mills, the consumption being 4 lb. per ton crushed.

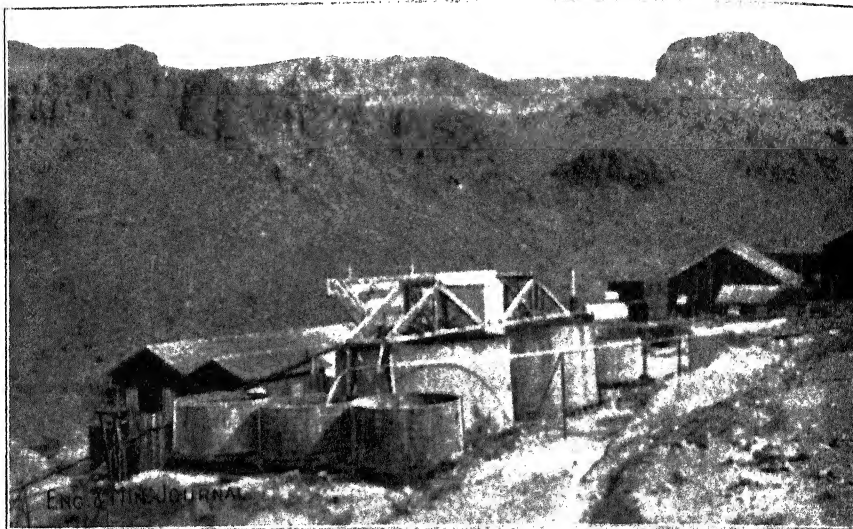
It has been practically found unnecessary to grind this ore through a 200-mesh screen, the product passing a 100-mesh screen giving as good extraction results. In practice, the pulp delivered to the agitation treatment contains about 86 to 87% which will pass a 150-mesh screen. The specific gravity of the dry slime has been determined and is stated to be 2.63, a figure denoting about medium weight.

Thickening and Agitation.—The entire pulp from the grinding system is received in two 30×10 -ft. Dorr thickeners, the overflow solution going to clarifying tanks and the underflow of thickened pulp being taken to the agitation system. This agitation installation consists of three 17×44 -ft. Pachuca tanks which were used in series, but, having found that so long a time for agitation was not necessary to secure highest extraction, this, together with the inherent inconveniences of this kind of tank, resulted in cutting out two of them and the using of only one.

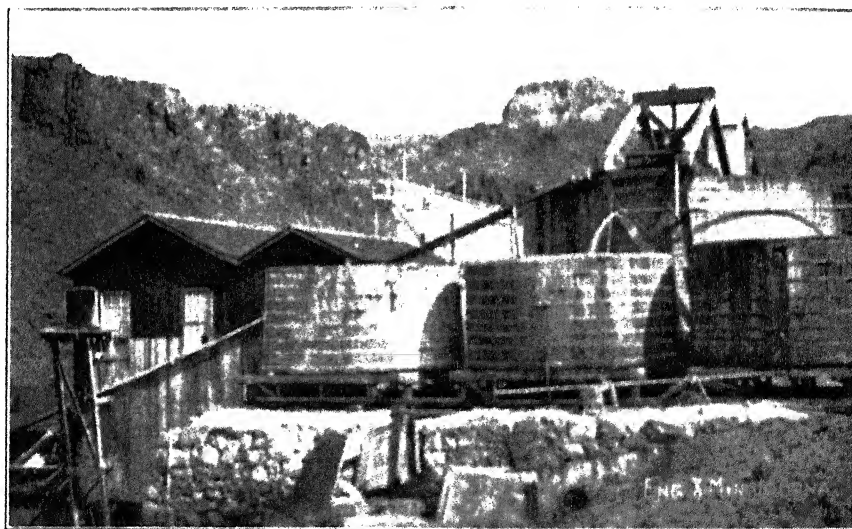
With the pulp of the grade and character customary at Gold Road, it is somewhat difficult to prevent settling of a portion on the solids, and in such cases the Pachuca tank has often been found unsatisfactory. Here the settlement became so great that the time of agitation was reduced to practically nothing. It is stated that the settlement was so hard and solid that one could step over the edge into the tank and walk about, keeping away from the center, without any inconvenience.

Thickened pulp, that coming from the thickeners into the agitation department, has the dilution ratio of about 1 to 1, and retains this consistency until after finishing the agitation treatment. Contact between the ore and cyanide solution was 36 to 48 hr. in the mill, counting from its first pulping at the cones, to its discharge. Owing to a change in the

metallurgical system, this time of contact may have become somewhat protracted, but not because of any necessity of increasing the per cent. c



THE GOLD ROAD MILL, AGITATION AND FILTRATION PLANT.



THE GOLD ROAD MILL, THICKENERS AND SOLUTION TANKS.

traction. The greater part of the extraction is secured before the agitation treatment, and practically none after it.

Issuing from the agitation system in the Pachuca tanks, the pulp

delivered to a series of thickeners where the pulp is successively dewatered and rediluted, thus washing out the dissolved metal in the pulp.

This treatment is not that which has been generally followed at the Gold Road mill. The former method, followed until a few months ago, involved delivering the slime from the agitation system into a slime-storage tank whence it was taken by a 120-leaf Butters filter installation and handled in the usual way. After the cake had been dropped from the filter leaves, it was mixed thoroughly in a tank containing mechanical agitators and discharged by gravity after passing an automatic mechanical sampler.

For many reasons, this system has been dispensed with and the pulp from the agitation system is delivered to two thickeners.

Filtration vs. Decantation.—The solution overflow from these thickeners is pumped back to the head of the mill and used as mill solution, while the thickened underflow goes to two more thickeners, before reaching which, however, it is diluted with solution previously precipitated. The solution overflow from this second pair of thickeners is sent back to dilute the pulp entering the first pair of thickeners. This solution, overflowing from the first pair of thickeners, does not require immediate precipitation as it consists largely of precipitated solution as has been shown. The first solution for precipitation is taken from the overflow of the Dorr thickener, through which the pulp passes before reaching the agitation system in the Pachuca tanks.

Second Thickening System.—As a final result, then, the pulp from the agitation system going into the first thickening unit, consisting of two pairs of thickeners, issues from it in form of a thick pulp of about the same consistency at which it entered, having been meantime diluted with barren solution, and twice thickened. The barren solution has passed through the pulp, diluted the metal-bearing solution, and carried most of its value to the mill solution circulation. From this circulation a great proportion of the solution passes to precipitation from the first Dorr thickener, which follows the tube mills, avoiding any extensive building up of value in solution.

Underflowing from the first thickening system, the thick pulp goes to a second system, which consists of three pairs of thickening tanks. In this unit the pulp is repeatedly thickened and washed, water in this case being the washing medium. The counter-current system is followed, water entering at the final thickener and progressing backward to the first of the series, the solids taking the opposite direction.

There is provided a separate precipitation circuit to accompany this washing unit, with facilities for diverting the solution either into the mill-solution circuit, before precipitation, or into the washing circuit itself after precipitation. The precipitate joins the bulk of that from the main

precipitation system, which is carried to the refining department. The movement of pulp and solution is graphically shown in the accompanying flow sheet.

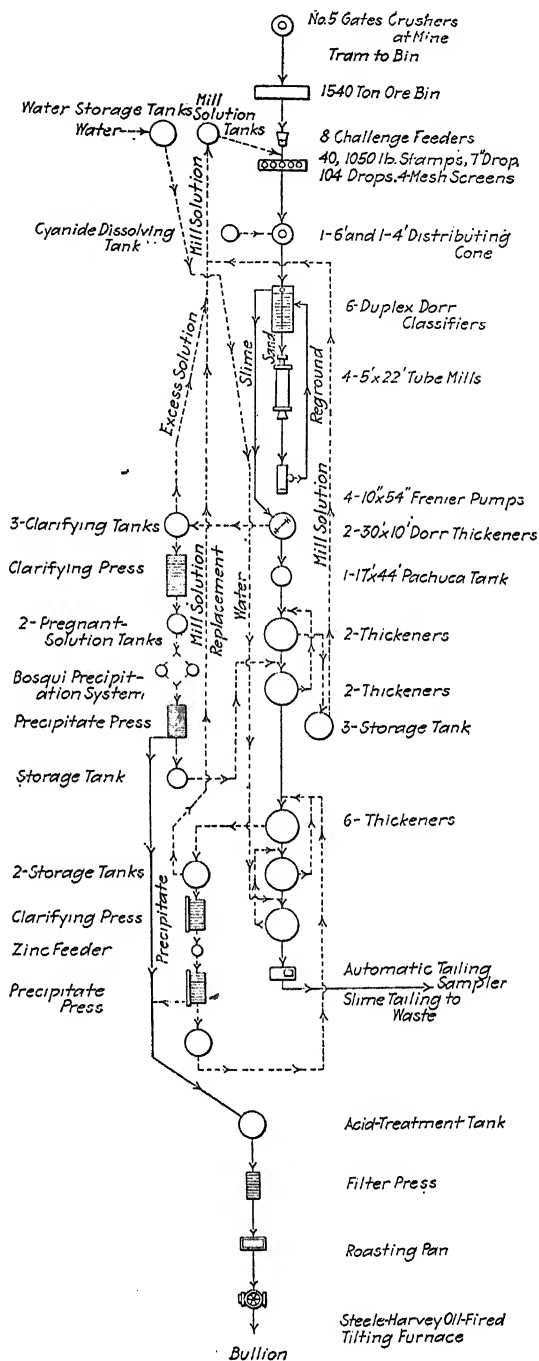
Preference for Decantation.—Undoubtedly, the adoption of this system will be regarded with interest by everyone connected with the process. Not merely is it interesting as an example of continuous counter-current decantation, noteworthy as it is from that point of view, but more particularly because that system has supplanted a large, modern, vacuum-filter installation with results, according to statement of the operators, better than those obtained under former method of operation.

There is food for considerable serious thought in this change, but there is danger of falling into popular form of error, and regarding the procedure as a reversion to a system already discarded, or, in other words, a step backward. A little thought, however, will make clear the fact that it is nothing of the kind, but rather a refinement of an earlier process, than which no change can be more progressive. It is clear to the most casual observer that the system used at the Gold Road mill is not applicable to all mills, although it may, as in the present instance, be applied occasionally with favorable results both as to percent of recovery and cost of operation. It is applicable in its present form only where solutions carrying low cyanide percentages can be used and where the amount of metal in solution is comparatively small, conditions which are manifestly present when low or medium-grade gold ores are treated. Where high-grade solutions are used, it would be impossible to use the system in this form because a large loss of cyanide would be entailed, but by following up the decantation with a form of continuous filtration which would reduce the moisture content of the residue to about 25%, the system is not only feasible, but advantageous. To steer clear of generalities is necessary for the intelligent consideration of any innovation, so that in estimating the value of this one, it must not be considered revolutionary nor reactionary, nor anything more than a simple, clear application of a newly developed system to a particular case.

Precipitation by Zinc Dust.—Solutions of both circuits are precipitated with zinc dust, the special feeders and presses being provided in each case, as is shown in the flowsheet. Square-frame presses are used, and not the triangular form usually found in Merrill installations. A variation of the general filter-press practice is the use of three filter coverings for each plate. The layer next the cake of precipitate is of filter paper, the intermediate one of light muslin, and the outer one of the usual canvas. The paper is removed and burned with each precipitate cake, the intermediate sheet lasts for several clean-ups, while the canvas, by careful cleaning, is made to last indefinitely.

The method of adding zinc dust to the solution is the Bosqui system,

THE GOLD ROAD MILL, ARIZONA



controlled by the Merrill Metallurgical Co. and, as is usual, the Trent agitator is used for emulsifying. The consumption of zinc dust amounts to about 0.4 lb. per ton of solution precipitated.

Precipitate is handled in the usual way. Formerly acid treatment was not resorted to, but at present a preliminary acid "cutting-down" is made and the mass of precipitate is then roasted. The dry product of the roasting pan is fluxed and melted in a Steele-Harvey oil-fired furnace.

Experience at this plant has been such as to demonstrate that solutions containing exceptionally low percentages of cyanide can be precipitated successfully when the percentage of lime carried is sufficiently high. Solutions containing as little as 2c. to 15c. in gold and very weak in cyanide, solutions from washing systems, are successfully precipitated by carrying high alkalinity.

As has already been mentioned, the lime is added at the mine crushing plant. The consumption amounts to about 0.65 lb. per ton treated. Treatment solutions usually carry 2 to 2½ lb. CaO , per ton of solution.

Cyanide in the Tube Mill. The regular addition of cyanide for keeping up the strength of mill solutions, is at the tube mill. This is often considered an excellent point for addition of cyanide, as it is immediately crushed and put into solution; besides, the energetic agitation in the mill, together with the somewhat elevated temperature, gives the best opportunity for dissolving the greatest possible quantity of metal.

Solutions, at the Gold Road mill, are carried at about 2 to 2½ lb. KCN per ton, only one strength being in use. The consumption is about 0.4 lb. per ton of ore treated.

Extraction of gold is usually about 94% or more, and is calculated by using the combined content of bullion produced and tailing discharged as the content of the ore milled. Recognizing the limitations of this system, careful duplication and check samples are taken continuously in various parts of the mill.

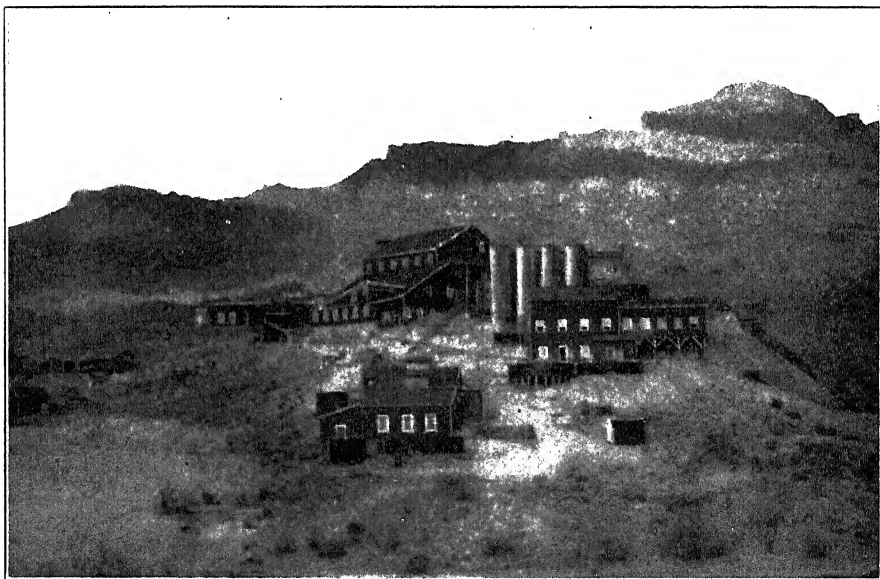
The total milling process requires 530 h.p. for its operation and 20 men are employed continuously, two of these being repair men.

Detailed cost data on this installation would be exceedingly interesting, but unfortunately the policy of the company is adverse to such publication, and for that reason no figures can be given. It may, however, be said that the expenses are altogether reasonable and in conformity with those found satisfactory in the best installations of its kind.

CHAPTER XIX.

TWO ARIZONA MILLS

The property of the Tom Reed Gold Mines Co. is situated in the western part of the state of Arizona, not far from the California line. The village of Oatman, which consists principally of the officers and employees of the Tom Reed Co., is not reached by the railroad, but communication is established at Kingman, about 20 miles distant. With Kingman,



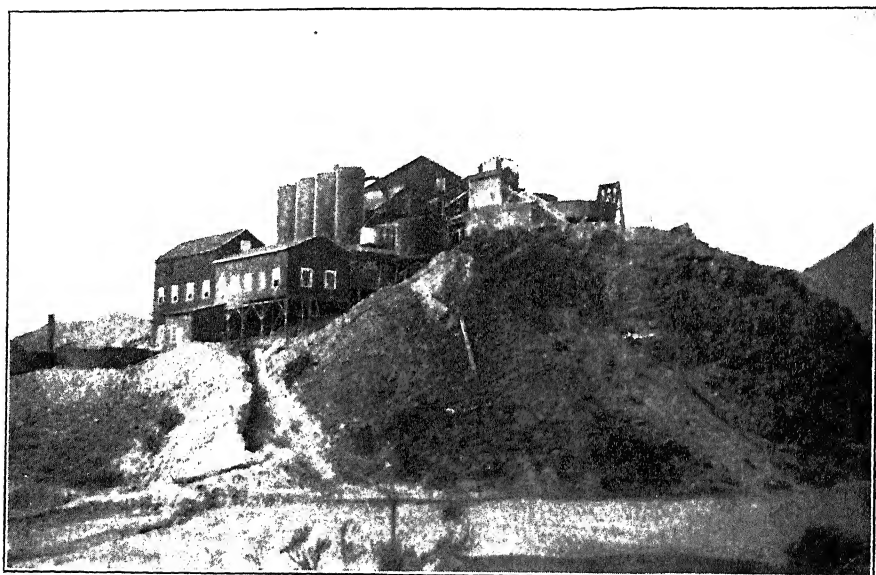
GENERAL VIEW OF TOM REED MILL, OATMAN, ARIZ.

transportation is by means of automobile stage for passengers; machinery and supplies are brought in on wagons and occasionally pack animals.

The situation is in a rocky, desert country, comparatively isolated, the nearest activity being at the Gold Road mine of the U. S. Smelting, Refining & Mining Co., about $1\frac{1}{2}$ miles distant. Aside from this large mine, there is nothing within a much greater distance. Water is scarce and its use has to be governed by great economy. The name of the company is taken from the name of one of the claims which comprise the property.

Character of the Ore.—Gold is the principal valuable metal in the ore, and it occurs generally free in quartz and, to a smaller extent in calcite. The ore is not particularly hard, but requires fairly fine grinding to free the gold and expose it to the action of cyanide solutions.

From \$15 to \$25 per ton is the general variation in the value of the ore treated in the mill and the average for several months at a time has been near the higher figure. While there is a small amount of silver occurring with the gold, it is not significant and no effort to save it would be worth while. At present the mill treats about 150 tons daily of dry ore, crushing with stamps and regrinding with tube mills. The total-sliming system



FILTER PLANT DISCHARGE AT TOM REED MILL.

of cyanidation is followed, crushing in cyanide solution containing 2 lb. KCN per ton. At the point where it is ready for the agitation treatment, the solids in the pulp will average about 70% through a 200-mesh screen and remaining on 100 mesh the quantity is about 1 to 2%, the whole making a product not particularly difficult to agitate.

Character of Material.—While pulp of this class may be difficult to agitate in those cases when it is largely heavy, granular and devoid of colloid constituent, the governing factor is usually, or ought to be, the fineness necessary to liberate the economically maximum amount of gold. The question of fine grinding has prompted vigorous partisanship for or against it by those metallurgists who believe strongly in extremes of fine grinding or no regrinding at all. Some maintain that extremely fine

grinding is wasteful and costly, and that if the grinding is not carried to extremes, agitation of the entire pulp is unnecessary and extravagant. Certainly there are several factors which must be given consideration. Primarily, of course, the cost of fine grinding must be weighed against the additional income furnished by it, and, to be truly profitable, this increased income must be sufficient to cover the cost of regrinding, interest and depreciation on the grinding plant, and leave a profit in addition. Even this comparison alone, however, is not sufficient to justify a proper decision. Part of the material reduced to the so-called state of slime is likely to be granular, though fine, and its agitation will cost more than if a true slime, or colloid matter, were being handled. This extra cost of agitation is not to be ignored in an exhaustive search for definite facts.

Contrary to what seems to be the general belief a large proportion of this fine granular material might be successfully leached provided only that it is well cleaned, that is, entirely freed of colloid material. If, and when, this granular material is sufficiently fine to liberate the contained metal and expose it to the action of cyanide solutions, it is more than likely that leaching will provide for recovery of an amount equal to that which could be obtained by agitation, at much less cost. Leaching will take longer to accomplish the same result, but the cost will be less and extraction will be as good in many cases. Also, the installation of a leaching plant costs less than that for agitation, and maintenance expenses and interest are therefore lower. In calculating the cost of leaching plants, however, it should not be forgotten that the separation, meaning a definite and clearly marked separation, of fine, granular material from a slime pulp is not a simple operation and is likely to cost an appreciable sum per ton treated. The most natural deduction is that every problem should receive separate study and be solved according to its requirements. At the Tom Reed plant, the grinding is carried to a fine point where the product is comparatively easy to agitate and gives better extraction; hence the total-sliming treatment.

Stamp-crushing.—At the Tom Reed mine the ore is hoisted and passed over a grizzly and through a No. 2 Austin gyratory crusher. Thus prepared, the ore is delivered to a long 16-in. conveyor belt which delivers it to the mill bin. From the bin, Challenge feeders supply a battery of 20 stamps of 1250 lb. each, dropping 105 times per minute through 6 in. The material is crushed to pass a 12-mesh screen. Crushing is done in cyanide solution containing 2 lb. KCN per ton and alkalinity equal to about 2 lb. CaO per ton of solution is carried.

From the stamps the pulp is received in a 6-ft. hydraulic cone, the slime overflowing to a circuit which will be described, and the sand going directly into the first tube mill.

Tube-milling and Classification.—Sand, or underflow, from the 6-ft.

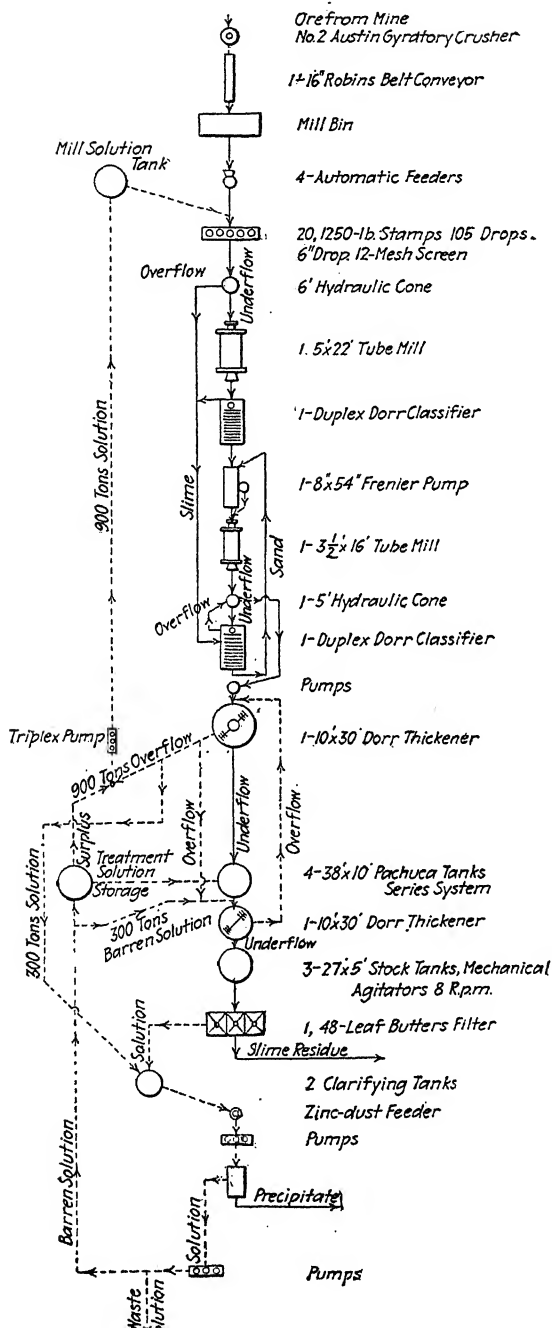
cone is fed into the first tube mill which is 5×22 ft., and equipped with El Oro lining. From this mill the entire pulp is delivered into a Dorr duplex classifier, from which the slime overflow joins the overflow from the 6-ft. cone first mentioned and the sand is delivered to an 8×54 -in. Frenier pump, and thence to the second tube mill. This mill is a small one, $3\frac{1}{2} \times 16$ ft., and is also fitted with the El Oro lining, which has given good results at this mill. The pebble consumption in these mills is 4 lb. per ton of ore crushed. This small tube mill delivers its product into another hydraulic cone, this one 5 ft. in diameter, whose overflow comprises the stream of total slime going to the agitation system. Its underflow is fed into a second duplex Dorr classifier, the overflow from which returns to the cone and overflows from there into the treatment circuit, while the sand product is taken to the Frenier pump which elevates it, for further grinding, into the small tube mill. It will be noted that the rather complicated flow of pulp through the grinding and separating machines is merely an exceptionally careful system of separating sand and slime so that the pulp for agitation may be uniformly and finely reground.

Agitation of Slime.—A 10×30 -ft. Dorr thickener receives the slime pulp now prepared for agitation, thickens it to a consistency of about 1:1 and delivers the thickened product to a battery of four 38×10 -ft. Pachuca tanks which are operated in series. During agitation treatment the solution is maintained at 3 lb. KCN per ton and 2 lb. CaO per ton. Due to the character of the ore, the chemical consumption of cyanide is so small that it may be disregarded. The total cyanide loss is $\frac{3}{4}$ lb. per ton of ore milled and is almost entirely mechanical. The lime consumption is about $\frac{1}{2}$ lb. per ton of ore treated.

Discussion of Filtration.—Pulp from the agitation tanks is received in another 10×30 -ft. Dorr thickener which delivers thickened pulp into a series of stock tanks which are equipped with mechanical agitators, in which the pulp is kept thoroughly mixed until ready for filtration. The overflow is returned to dilute the inflow into the first thickener, the solutions being disposed of, as shown in the accompanying flow sheet. A 48-leaf filter of the stationary vacuum type, or Butters system, is used for filtration, and, although it has proved satisfactory, it will probably be replaced by continuous decantation in the near future, experience and experiments having shown that system to be more economical and quite as efficient. Tailing from the filtering tanks is discharged by gravity into a dam, where the material is skimmed at intervals, as has already been described.¹

Solutions from the filtration plant are precipitated and returned to a treatment-solution storage tank, from which the solution for treatment is drawn. Any surplus at this point may be returned to the mill-solution

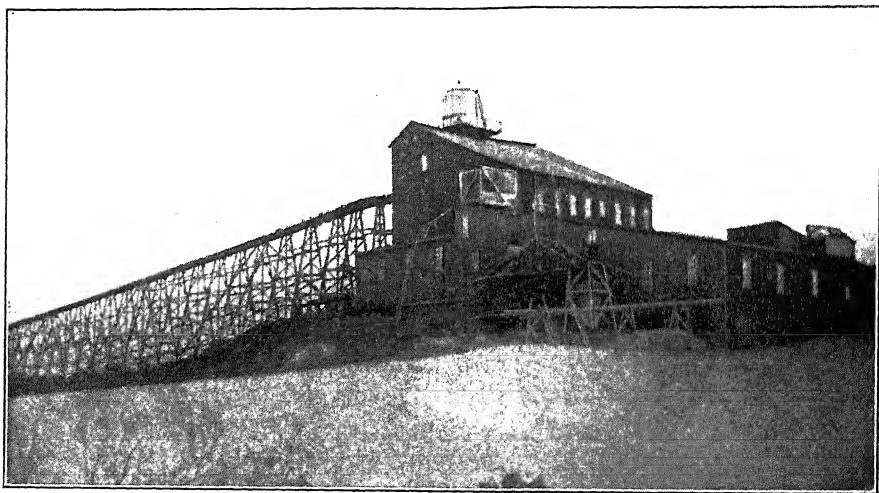
¹ "Eng. and Min. Journ.," Mar. 22, 1913; p. 618.



tank at the head of the mill, thus maintaining a solution balance without difficulty.

Precipitation Method.—Zinc shavings have been used for a long time for precipitating the gold from cyanide solutions at the Tom Reed mill, but recently the system was changed and the Merrill zinc-dust apparatus installed. The system gives entirely satisfactory results, 420 tons of solution being precipitated in a plant designed to handle only 300 tons. With zinc shavings, the consumption of zinc amounted to 0.25 lb. per ton of ore treated, while with zinc dust only 0.15 lb. is necessary.

The mill crushes an average of 150 tons per day, requires 134 hp. for its operation, and employs 16 men for its regular control. Pebble consumption in the tube mills amounts to 4 lb. per ton of ore crushed. While itemized cost data is not obtainable, the aggregate is \$2.50 per ton milled, including the depreciation account. Average extraction is 95% of the gold in the ore.



THE VULTURE MILL, WICKENBURG, ARIZ.

The Vulture Mill.—The property of the Vulture Mines Co. is situated about 14 miles southwest of Wickenburg, in central Arizona. The country is practically desert, and water is scarce. There is no available wood for fuel, and, as coal is extremely expensive laid down at the mine, distillate and oil are used entirely to furnish motive power. Power for the mill is furnished by two 150-hp. Nash engines, which are entirely satisfactory.

The valuable metal is gold, which occurs in white quartz, together with pyrite and small quantities of galena and chalcopyrite, sometimes banded and sometimes occurring in masses with the pyrite. The present

orebody is one which was discovered in 1911, the vein having been faulted and the ore entirely lost. The mine is an old one, having been discovered by H. Wickenburg in 1863. Surrounding country rock is dioritic schist, no igneous intrusions having any influence on the ore deposition. The average milling ore contains gold to the value of approximately \$20 per ton. Mine ore is trammed a short distance from the working shaft to the crusher bins, from which it is fed to a gyratory crusher. The crushed ore, which passes a 2-in. ring, drops to a conveyor belt, and is elevated to another ore bin. From this the ore is hoisted over a trestle 700 ft. long to the mill bins by means of a friction hoist on the mill line shaft.

Regrinding in Pans.—The stamp installation consists of twenty 1600-lb. stamps, dropping 98 times per minute through $6\frac{1}{2}$ in., and crushing through a 40-mesh round-aperture screen. Chuck blocks are used, and the ore is subjected to amalgamation inside the mortars.

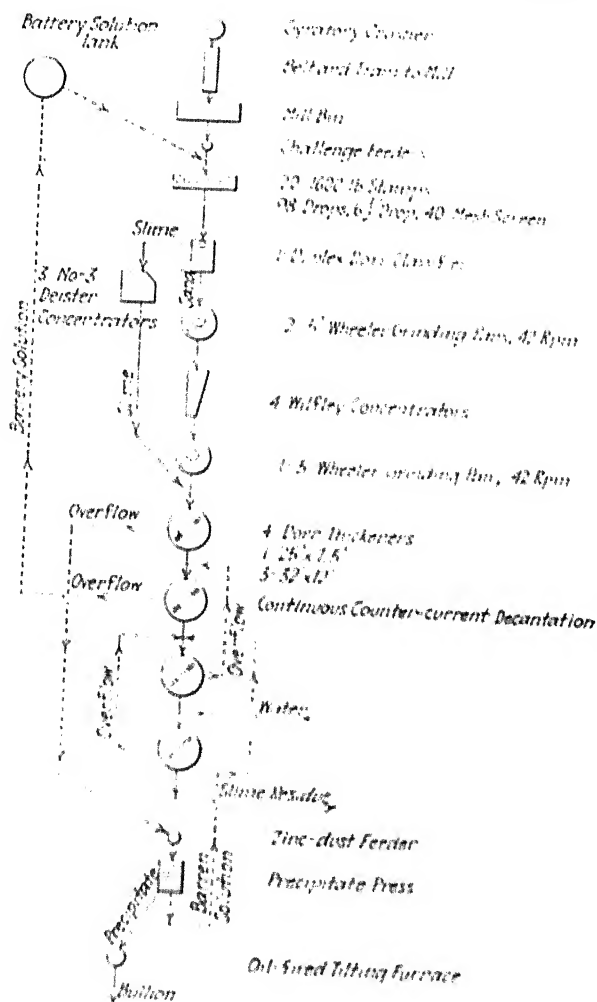
A Dorr duplex classifier follows the stamps, and separates the pulp into sand and slime. Solution is used throughout the mill, including the stamp crushing department. The slime portion of the ore is elevated to three Deister slime concentrators, the tailing from which is taken to a series of thickeners. The classified sand is reground in two 5-ft. Wheeler pans, which make 42 r.p.m., and each is capable of grinding 35 tons per day, 85% of which passes a 100-mesh screen. The consumption of iron amounts to about one pound per ton of ore treated.

Continuous Decantation without Filtration.—From the two grinding pans, the ground pulp passes to four Wilfley concentrators, the high-grade sulphide being here removed, and the tailing from the tables is again reground in a third Wheeler pan, identical with the other two. The product of this third pan is sent directly into the first of a series of continuous thickening tanks, together with the slime from the Deister concentrators. In this series of thickeners, there is continuous decantation and thickening of pulp, followed by a thinning by means of weaker solutions. Water for final washing enters the last thickener and progresses to the first in a direction contrary to that of the moving pulp. The accompanying flow-sheet diagram shows the movement of the pulp and solutions in the thickener series, as well as in the rest of the mill. No filter is in use and the final thickener is required to discharge the pulp at the maximum possible thickness. It will be noted that there are no tanks for agitation of the pulp, the operation being practically grinding, concentrating, washing and discharging. The operators, however, believe that better results could be obtained by using one or two agitation tanks ahead of the thickener series, and such tanks will probably be installed in the near future.

Zinc dust is used as a precipitant, a feeder of the belt type being installed. A precipitate press of the Merrill triangular type having sixteen 36-in. frames is used to collect the precipitate, which is not acid treated,

but is melted directly in an oil-fired tilting furnace and the bullion shipped. Slags formed in the melting are periodically smelted in a small blast furnace, the lead bullion cupelled and the product added to the regular output of the mill.

It is of particular interest to note that in the two modern and efficient



FLOW SHEET OF VULTURE MILL.

plants described here, experiment has shown that expensive filtration plants may be considered superfluous. At the Tom Reed mill, where a filtration plant was originally installed, it will be superseded by continuous decantation, resulting in a material economy, while at the Vulture, no filter has been installed, the series of four thickeners satisfactorily doing

the work. In practice the thickeners deliver a product which is acceptable from the point of view of contained moisture. The first of the series at the Vulture mill delivers a product containing 31% moisture; the second, 43%; the third, 42%; and the fourth and final one, 35% moisture. If necessary, the thickener can deliver a product containing as little as 25% moisture on a slime which settles rapidly. It is not too much to say that on the same material, the vacuum filter cannot do a great deal better than the thickener, considering all points at their real value. In the statements that are made here in this connection, reference is made solely to the treatment of gold ores of milling grade. Silver ores, requiring solution of greater cyanide strength, may be treated by a variation of the system which will be mentioned in a later article.

Extremely fine grinding is not required on the Vulture ore to secure the economically maximum extraction. Classification stated in the accompanying table shows the condition of the pulp undergoing treatment.

CLASSIFICATION OF SLIME PULP

+ 80 mesh.....	12.0%
+100 mesh.....	2.5%
+150 mesh.....	23.5%
+200 mesh.....	46.5%
-200 mesh.....	45.5%

Solution is used throughout the mill, usually maintained at about 2.1 lb. KCN per ton of solution. Lime is added at the mortars in sufficient quantity to maintain an alkaline condition.

About 1 lb. of KCN is consumed in treatment, 2 lb. of lime and 0.4 lb. zinc, in the form of zinc dust. Costs, while not at present available for publication, are reasonable in view of the adverse conditions already mentioned. These Arizona plants are particularly instructive as examples of first-class operation under difficulties.

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